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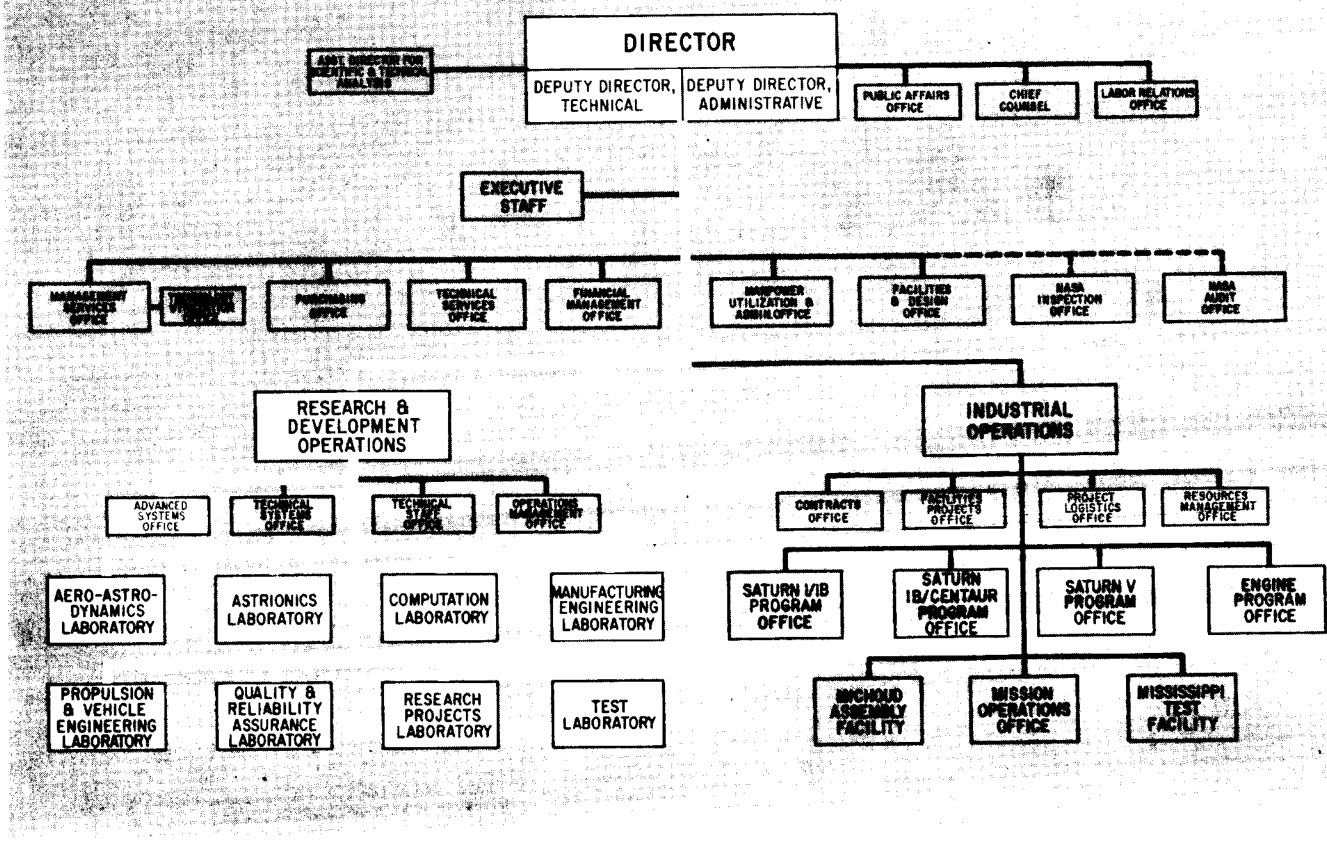
RESEARCH ACHIEVEMENTS REVIEW SERIES NO. 5

RESEARCH AND DEVELOPMENT OPERATIONS
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

GEORGE C. MARSHALL SPACE FLIGHT CENTER



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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C.

ELECTRONICS RESEARCH AT MSFC

RESEARCH ACHIEVEMENTS REVIEW SERIES NO. 5

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1965

PREFACE

In 1955, the team which has become the Marshall Space Flight Center (MSFC) began to organize a research program within its various laboratories and offices. The purpose of the program was twofold: first, to support existing development projects by research studies and second, to prepare future development projects by advancing the state of the art of rockets and space flight. Funding for this program came from the Army, Air Force, and Advanced Research Projects Agency. The effort during the first year was modest and involved relatively few tasks. The communication of results was therefore comparatively easy.

Today, ten years later, the double purpose of MSFC's research program is still the same. Funding for the program now comes from NASA Program Offices. The present yearly effort represents major amounts of money and hundreds of tasks. The better part of the money goes to industry and universities for research contracts. However, a substantial research effort is conducted in-house at the Marshall Center by all of the Laboratories. The communication of the results from this impressive research program has become a serious problem by virtue of its very voluminous technical and scientific content.

The Research Projects Laboratory, which is the group responsible for management of the consolidated research program for the Center, initiated a plan to give better visibility to the achievements of research at Marshall in a form that would be more readily useable by specialists, by systems engineers, and by NASA Program Offices for management purposes.

To initiate the plan, monthly Research Achievements Reviews have been established, repetitive over a yearly cycle, with each review covering one or two fields of research. These verbal reviews are documented in the Research Achievements Review Series.

Ernst Stuhlinger
Director, Research Projects Laboratory

These papers presented April 29, 1965

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N66-23457

OPTICAL TECHNOLOGY PROGRAM

By

Joseph L. Randall

SUMMARY

A research and development program in optical and infrared technology is described in this review. The purpose of the program is to develop advanced optical systems for guidance, tracking, and communication in aerospace missions. The program is divided into four categories: (1) component and device development, (2) technique development, (3) in-house supporting research and development, and (4) optical system study and development.

Component and device development deals with laser sources, detectors, modulators, beam scanners, and ring lasers; all for use in optical systems. Superheterodyne receiver development and laser frequency stabilization compose the technique work, the aim of which is the development of communication and tracking techniques for particular systems.

In-house research and development, which provide essential support for the entire program, include the theoretical and experimental study of the effects of the atmosphere in optical tracking and communication and the design, fabrication, and evaluation of optical lenses, mirrors, and telescopes. The part of the optical system study and development discussed in this review refers to an optical technology satellite program, which has two important purposes. One is the development of an optical system for deep-space communication. The other is the determination of the effects of space environment on large diffraction-limited optics in order to obtain engineering data which can be used for designing 250 to 500 cm telescopes.

I. INTRODUCTION

With the development of the coherent light source (laser) in 1960, its potential for optical tracking and communication became apparent. Optical systems, compared to conventional RF techniques, should require smaller antennas, use less power, weigh less, give greater tracking accuracy, and increase deep-space communication capability. However, considerable research will be required to develop optical systems that will be practical and reliable. Marshall Space Flight Center has been engaged in an optical technology research and development program for several years with the aim of developing advanced optical systems for aerospace use.

This review will discuss the optical technology program, which is conducted in house and through out-of-house contracts. At present, most of the program is being carried on out of house under approximately 20 contracts.

The program is divided into (1) components and devices, (2) techniques, (3) supporting research and development (in-house), and (4) optical systems. The purpose of the component and device work is to develop better laser sources, detectors, optical modulators, beam-scanning devices, ring lasers, etc., for use in optical systems. The technique work is aimed at the development of communication and tracking techniques for use in a particular system. The in-house research and development work supports the overall program and allows the laboratory to maintain its technical competence. Examples of such work include the design, fabrication, and evaluation of optical lenses, mirrors, and telescopes used on other in-house projects; and the theoretical and experimental study of the effects of atmosphere on optical tracking and communication. The optical systems now being studied or developed are: (1) a precision optical tracking system for advanced launch vehicles, (2) an optical guidance system for rendezvous of spacecraft, and (3) an optical technology satellite system. Each of these systems will be discussed in detail, the latter in this report and the first two in the report on laser research (Wyman).

Figures 1 through 10 illustrate the extent to which Astrionics Laboratory is equipped for its research and development programs.

II. COMPONENTS AND DEVICES

The development of components and devices includes laser sources, detectors, modulators, beam scanners, and ring lasers.

A. SOURCES

For communication and tracking, it is desirable to have continuous wave (cw) operation or a pulsed laser that has a high repetition rate; therefore, research and development have been aimed toward these ends. Research in these sources can be divided into three areas: solid-state optically pumped lasers, semiconductor injection lasers, and gas lasers.

1. Solid-State Optically Pumped Lasers. In this area the goal has been to develop a cw, room-temperature laser that is efficient and practical. In 1963, Marshall Space Flight Center awarded a contract to the Linde Company to grow crystals that could be evaluated spectroscopically for potential laser materials. In this way, many materials were studied. This contract led to the development of yttrium aluminum garnet doped with neodymium ($YAG{:}Nd^{+3}$). This material is now used in the most practical cw solid-state optically pumped laser. It operates cw at 1.06 microns, is water cooled at room temperature, and is pumped with a tungsten lamp. It operates for extended periods with little degradation, and outputs of over one watt have been achieved. Figure 11 shows the cavity and laboratory setup. Its limitations are that the overall efficiency is less than one percent and that the output is not diffraction limited as is that of a gas laser. A contract is now in effect with the Linde Company to improve the optical homogeneity of the laser material. It is hoped that this will improve the diffraction-limited narrow beam. In-house work will be done to evaluate the performance of the Linde-grown rods for better efficiency and beam divergence and to design and build laser cavities to increase the power output to several watts. A continued effort will be made to improve $YAG{:}Nd^{+3}$ as a laser material.

2. Semiconductor Injection Lasers. Semiconductor injection lasers, because of their small size and high efficiency, offer great promise as spaceborne laser sources. They have a disadvantage, however, in that their emitting aperture is very small and is rectangular. This means that the emitted beam is very broad (several degrees). In general, the output is not diffraction limited to the aperture size. Thus, the power output per solid angle is not nearly as good or usable as that of gas lasers for applications in which tight beam divergence is a necessity. However, for some applications, such as the optical guidance system for rendezvous, it is very good because a very tight beam is not desired.

Marshall Space Flight Center is now sponsoring research in two areas: basic research in operation of semiconductor lasers and development of a gallium arsenide diode laser array. The basic research contract, with Carnegie Institute of Technology, is for the study of the basic physics of operation. It is expected that the study will yield information leading to the design of better lasers. The laser array contract, with Radio Corporation of America, calls for the development of an array that will give outputs of 50 watts peak on a pulsed basis at several kHz. At the start, it was expected to operate at 77°K; now it appears that the goal can be achieved at room temperature. This development is in support of the optical guidance system, and it is hoped that this source will increase the acquisition range.

3. Gas Lasers. Gas lasers have the property of being diffraction limited and, consequently, can be beamed through a large telescope to project extremely narrow beams (of the order of 1 arc second or less, depending upon the telescope primary size). The gas laser is the only laser that has this advantageous property. The disadvantageous feature of gas lasers is a low overall efficiency (a few hundredths of a percent). For ground-based beacons in tracking and communication, however, this is not a serious drawback.

The only gas laser work sponsored out of house has been the development of a special gas laser for the precision optical tracking system being developed by MSFC. This laser (50 by 20 by 20 cm) will produce 50 mW cw at 6828Å, and a beam width no greater than 25 arc seconds.

Recent work with argon and the rare-gas ionized laser has been very impressive. For instance, it was recently reported that 8 watts total cw in effectively two lines (at 5145Å and 4880Å) has been achieved. The limitation in this laser is that of developing dielectric reflectors to act as the cavity end plates that do not burn up at such power levels. It is anticipated that this problem will be solved in the near future and power outputs of up to 100 watts are expected early in 1966. These argon lasers are inefficient; however, the output is diffraction limited and should be the answer to the ground beacon for deep-space optical communication systems. At present, the argon laser is the best choice for the ground beacon for the optical technology satellite system. No work on the argon laser has been sponsored by MSFC, but future plans call for its development.

B. DETECTORS

In the visible and near infrared spectrum, two types of detectors are useful for tracking and communication: photoemissive surfaces, as used in photomultipliers, and semiconductor junction detectors, in which photons create electron hole pairs that are detected.

1. Photomultiplier Tubes. Photomultiplier tubes are sensitive in the visible wavelengths; the sensitivity is low from about 0. 8 to 0. 9 micron on to longer wavelengths. The quantum efficiency (photo electrons to incident number of photons) is low, but efficient detection is possible because of the low-noise amplification process of 10 dynodes with gains of 10^6. The frequency response is limited to a few hundred MHz. For coherent or superheterodyne detection, where relative velocity between the spacecraft and earth may cause optical Doppler shifts as high as 10 to 20 GHz, higher frequency response is desired.

2. Semiconductor Diode Detectors. Semiconductor diode detectors have high quantum efficiencies from the visible wavelengths to as high as 6 to 7 microns. The frequency response is limited partly by the capacitance of the p-n junction and, since these diodes are of the order of 25 microns on a side, the frequency response can be high and therefore advantageous for coherent detection. For some applications, the small size is a disadvantage. Also, even though the quantum efficiency is almost one, careful design is necessary to amplify the signal so that the signal-to-noise ratio is equivalent to that obtainable in the photomultipliers.

In 1963, MSFC sponsored work by Philco Corp. on the development of high-frequency-response diodes for the visible and near infrared spectrum for use in coherent detection. A result of this work has been the development of GaAs, Si, and Ge diode detectors which have frequency responses in the order of 8 to 10 GHz. These detectors are the fastest known today and have been made commercially available to the laser research community. They are widely used now in many laboratories. Philco still is under contract with MSFC, and the present and future research plans call for further development in which some gain may be incorporated in the diode without increase in noise. It is hoped that larger detector areas will be developed to enhance their use, while there will be little decrease in frequency response.

MSFC has not sponsored out-of-house contract work on photomultiplier detectors. The main emphasis has been on procuring commercially available photomultipliers and evaluating their sensitivity and frequency response. In addition, work is being done in house to improve the shielding against background pickup. Figure 10 shows a specially designed photomultiplier housing and the setup for evaluation.

C. MODULATORS

For the transmission of information by optical beam, the beam must be modulated in some manner. For high rates of data transmission, the modulators must have a wide bandwidth. The most efficient way to modulate a gas laser or an optically pumped solid-state laser is to modulate the cw laser beam outside the laser cavity. Semiconductor injector lasers, however, may be amplitude modulated by directly modulating the current into the laser. MSFC has worked with commercially procured electro-optic and interference modulators, evaluating their performance for the laser system being developed. In addition MSFC has worked on circuit design for the modulation of semiconductor injector lasers to be used with a pulse position modulation communication system.

D. BEAM SCANNERS

In many cases it is desirable to scan an optical beam for an acquisition operation. Where high-frequency scanning is desired, mechanical modulators are not serviceable. A device with an electrical input to control the beam with very little mass motion would be ideal. In 1963, MSFC awarded a contract to General Telephone and Electronics Co. to develop a beam scanner. This device, which uses piezoelectric shear plates to scan an optical beam, will scan up to 2 kHz and will deviate the beam to about 1 degree. The deviation in this case corresponds to about 100 spot diameters. Each scanner deflects the beam in one direction; therefore, two scanners are used to achieve a two-directional scan. Figure 12 shows the laboratory setup of a two-dimensional beam scanner and a rectangular scan pattern of the beam on a wall. This system will be used as a part of the acquisition system for precision optical tracking.

E. RING LASERS

A very interesting device developed since the conventional laser was invented is the ring laser, an angular motion sensor. In the ring laser the cavity is formed by three or more mirrors rather than by two. The cavity will oscillate as it does in the conventional laser when the resonance condition of the length equals an integral number of half wavelengths. This resonance condition can be satisfied for a wave moving clockwise and a wave moving counterclockwise. If the ring is allowed to rotate, the path length is longer for one wave and shorter for the other wave; hence, the resonant frequency is increased for one wave and decreased for the other wave. If the two waves are then optically mixed on a photodetector, the difference frequency is obtained. This frequency is proportional to the angular velocity.

MSFC is now sponsoring work with Sperry Gyroscope Co. and Perkin-Elmer Corp. to study the basic properties and to determine the ultimate sensitivity of the ring laser as a rotation sensor. The most obvious application would be to use it in a guidance system on a space vehicle. In addition, it might be used for accurate angular motion sensing on a tracking pedestal. Such devices are planned for use on the pedestal of the precision optical tracking system under development if the angular rotation sensitivity is sufficient. The contracts with Sperry and Perkin-Elmer call for a sensitivity of 1 degree per hour (or 1 arc second/second). This device is contained in a triangular case 38 cm high, 68.6 cm on the base, and 12.7 cm thick. Indications at this time are that the sensitivity of 1 degree/hour will be obtained by early 1966. The plans for future research aim at increasing the sensitivity to 10^{-3} degrees/hour (or 10^{-3} arc second/second).

III. TECHNIQUES

Techniques development is divided into superheterodyne receiver development and laser frequency stabilization development.

A. SUPERHETERODYNE RECEIVER DEVELOPMENT

Coherent or superheterodyne detection is more sensitive than incoherent detection in receiving in the presence of a high-level background. For no background light, the coherent receiver gains nothing as compared to a receiver using predetection narrowband filtering or incoherent detection. However, since there will be background light for almost all applications envisioned, development of the coherent receiver is warranted.

Coherent detection is more complicated than straight AM detection. Coherent detection is the optical mixing of two light waves of different frequency; the phase of the two waves must always remain spatially constant for optimum heterodyning. This means that the optics in the receiver must not distort the received wavefront, and the local oscillator must be frequency stable so that the beat frequency will be constant. The atmosphere tends to destroy the spatial coherence so that the received signal is not coherent across the receiver aperture. This has the same effect as poor quality optics, namely, that of degrading the output signal. Since the atmosphere distortion changes with time, the output signal from the receiver will be randomly modulated in amplitude and difference frequency. In spite of the problems, the coherent receiver offers great potential, especially outside the atmosphere.

MSFC now has a contract with Sylvania Corp. to design and fabricate an optical superheterodyne receiver capable of receiving modulated laser signals such as might be used in space communication. This receiver must be capable of accounting for the large optical Doppler shifts which change the carrier frequency when large velocities exist between the transmitter and receiver. This receiver is being designed to track a transmitter to 0.1 mrad and account for Doppler shifts up to 0.5 to 1 GHz.

Future plans call for development of the transmitter and for establishment of a communication link to evaluate and improve the technique.

B. FREQUENCY STABILIZATION OF LASERS

As previously mentioned, frequency stable lasers are needed for superheterodyne receivers. However, stabilizing the frequency of a laser is no small task. For this reason, frequency stabilization work is being conducted on contract separate from the superheterodyne receiver work. The Technical Research Group is now under contract with MSFC to develop a HeNe laser operating at 6328Å and stable in frequency to 1 part in 10^{11}. The current program is to develop a prototype model demonstrating the stable laser. Future plans are to design a more practical field model which may be incorporated into the superheterodyne receiver.

IV. IN-HOUSE SUPPORTING RESEARCH AND DEVELOPMENT

As part of its support of the overall program in optical technology, MSFC has an in-house research and development program in selected areas. This serves to maintain technical competence in house, which in turn is necessary for effective direction of out-of-house work. The in-house work program consists of (1) optical design, fabrication, and evaluation, (2) atmospheric measurements, and (3) spectroscopic measurements.

A. OPTICAL DESIGN, FABRICATION, AND EVALUATION

Optical design for many components and telescopes used in in-house research is being done with the aid of a computer. Limited fabrication and evaluation are now being performed. The Pilot Manufacturing Branch at MSFC is setting up an optical shop in which lenses, mirrors, and flats up to 20 cm can be made. The Applied Research Branch is engaged in a program to set up facilities and establish techniques for evaluating nearly all optical components purchased outside or fabricated in house. Multilayer dielectric filters, reflectors, and coatings can now be made at MSFC.

B. ATMOSPHERIC MEASUREMENTS

In support of the precision optical tracking system and optical superheterodyne receiver work, atmospheric effects on laser beams are being studied. Measurements are being made on atmospheric effects on coherent mixing and on angular deviation of a laser beam by the atmosphere. The measurements have been made in the dome situated east of Astrionics Laboratory. Many measurements have been made with optical path lengths up to 3 kilometers. Figures 7 and 8 show experimental facilities for these measurements.

C. SPECTROSCOPIC MEASUREMENTS

As previously mentioned, lasers of all types have been measured and study in which spectroscopic and electronic analysis of the output is made is continuing.

V. OPTICAL TECHNOLOGY SATELLITE SYSTEM

The optical technology satellite program has two purposes. The first is to develop a two-way optical system for use in deep-space communication. The second is to determine the effects of space environment on large diffraction-limited optics to obtain engineering data useful in the design of 250 to 500 cm telescopes of future space observatories.

One of the more serious problems facing NASA in its deep-space missions is how to transmit large quantities of data from spacecraft to earth. Theoretical studies have shown that, because of its narrow beam divergence, the optical communication system may prove superior in some respects to microwave communication systems, provided that certain problems peculiar to optical communication can be solved. One of the most serious problems is how to point such narrow beams (0.2 to 1 arc sec) accurately enough to hit a receiver.

It has been said that, in the future, astronomy will require large diffraction-limited telescopes in space laboratories. However, there have been no orbital flights of large diffraction-limited optics nor are any planned. Orbiting such a system has two equally important purposes. The first is to develop the techniques for establishing two-way optical communications for use in deep space. The second is to determine the effects of the space environment on large diffraction-limited optics. It would be planned to monitor the figure of the primary mirror and to make corrections, if possible, to bring it back to the diffraction limit.

A study has been performed for NASA by the Perkin-Elmer Corp. to examine the problems and to make a preliminary conceptual design of the satellite and ground station necessary to perform selected experiments.

Experiments have been chosen to simulate deep-space communication for ranges up to 160 million kilometers. The following experiments have been chosen tentatively:

1. Atmospheric scintillation effects on coherent beams.
2. Atmospheric effects on plane and circularly polarized light.
3. Remote manual optical alignment on earth by an eye/hand servoloop.
4. Optical heterodyne detection on earth.
5. Optical heterodyne detection on the satellite.
6. One-tenth arc second tracking in the satellite.
7. Point ahead.
8. Space-to-ground-to-space loop closure.
9. Tracking in the presence of spacecraft motion.
10. Telescope suspension system.
11. Transfer of tracking from one ground station to another.
12. Earthshine effects on acquisition and tracking.

13. Optical communication system with a bandwidth of 10 MHz.

14. Onboard determination of the effects of space environment on large diffraction-limited optics.

A conceptual design (Fig. 13) of how these experiments might be performed has been made.

A synchronous circular orbit with the orbit plane tilted 50 to 60 degrees to the equatorial plane has been tentatively chosen to simulate the angular tracking rates encountered for the deep-space conditions and to allow continuous observation and communication.

Preliminary weight estimates for the satellite are shown in Figure 14. A Saturn-IB Centaur would be capable of placing this load in synchronous orbit. Preliminary estimates of power consumption are shown in Figure 15.

Future plans call for preliminary design study under the AES program that would include design of the integrated experiments, spacecraft, and ground station based on the conceptual design.

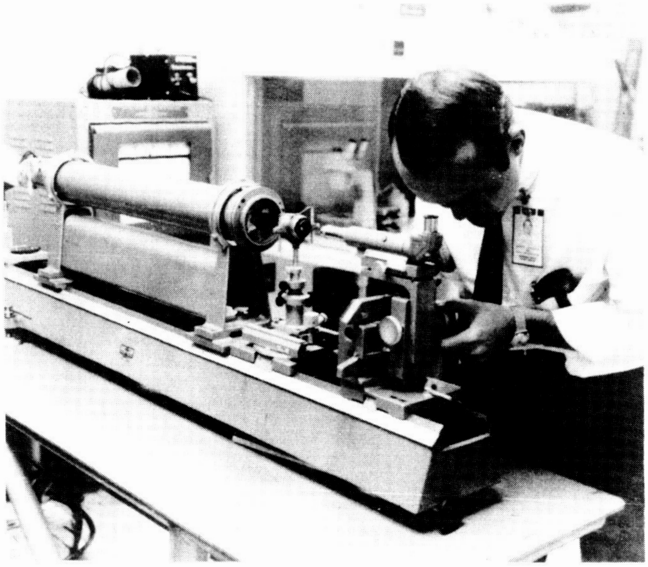

FIGURE 1. LENS PARAMETER MEASUREMENTS

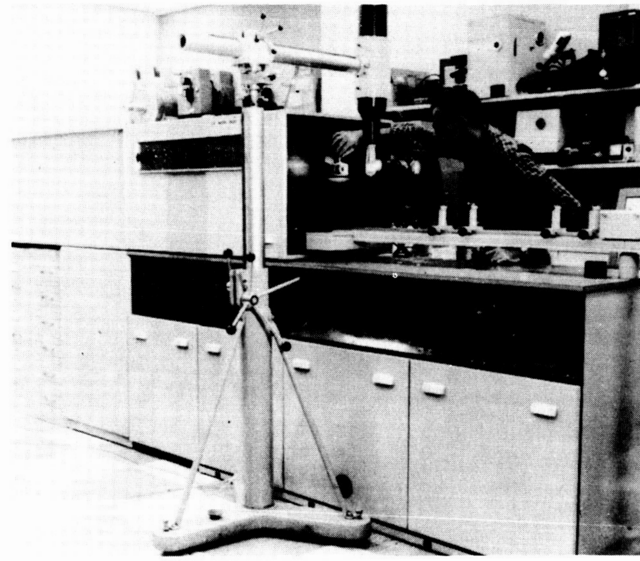

FIGURE 3. JARRELL-ASH SPECTROGRAPH

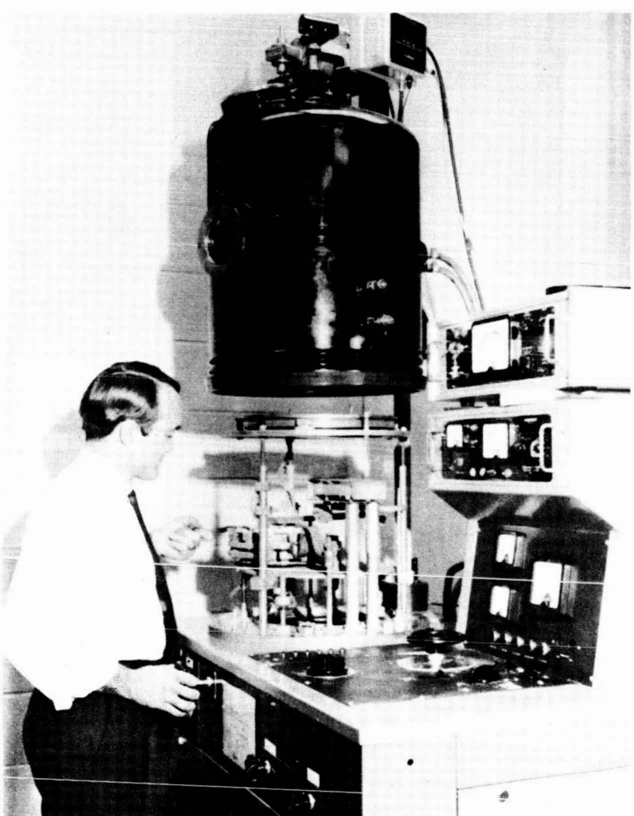

FIGURE 2. THIN-FILM DEPOSITION AND VACUUM CHAMBER

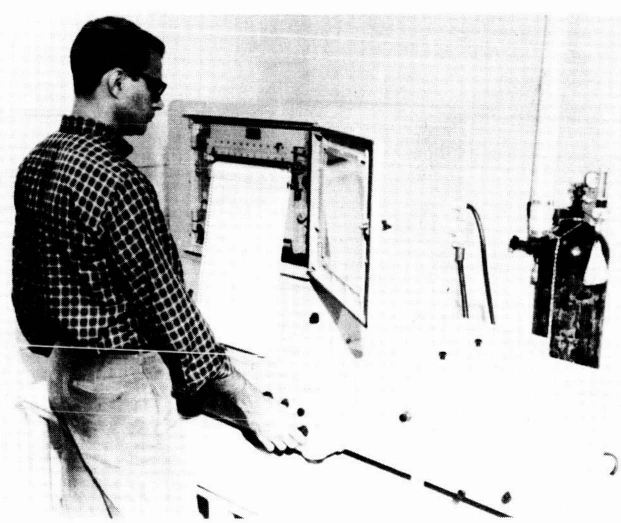

FIGURE 4. CARY SPECTROPHOTOMETER

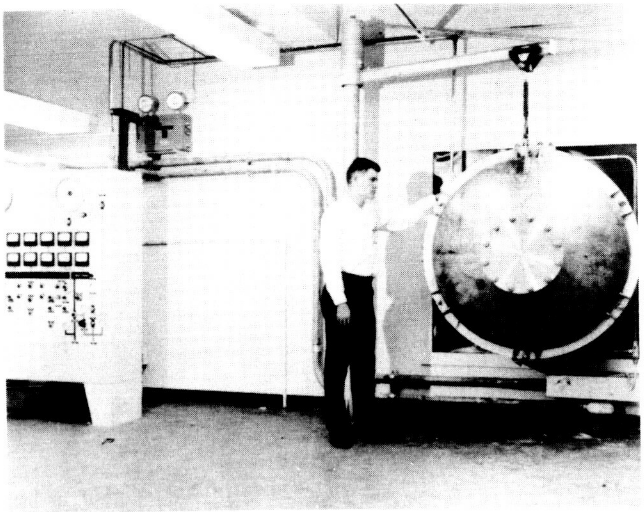

FIGURE 5. CONTROL ROOM FOR EVACUATION OF OPTICAL TUNNEL

FIGURE 7. OBSERVATORY DOME FOR LASER ATMOSPHERIC EXPERIMENTATION

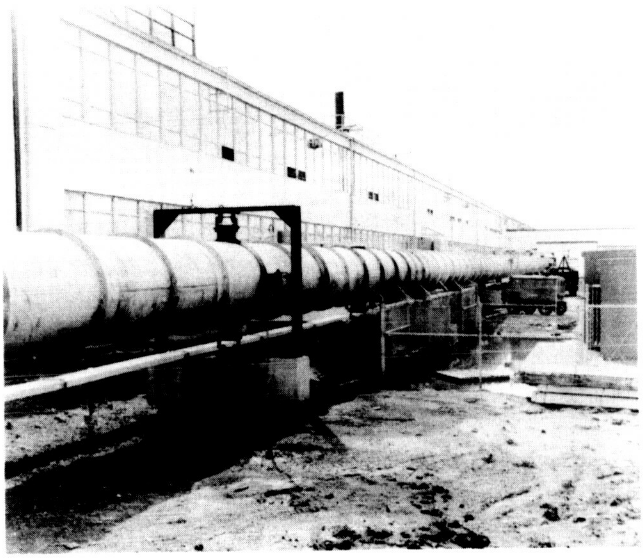

FIGURE 6. VACUUM TUNNEL FOR OPTICAL EXPERIMENTS

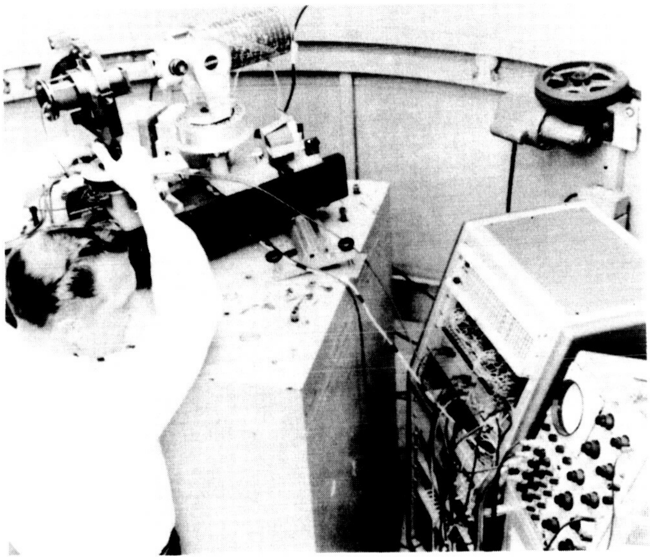

FIGURE 8. ATMOSPHERIC ANGULAR FLUCTUATIONS MEASURING SYSTEM

FIGURE 9. OPTICAL DOPPLER SHIFT USING CONSTANT-VELOCITY RECIPROCATOR

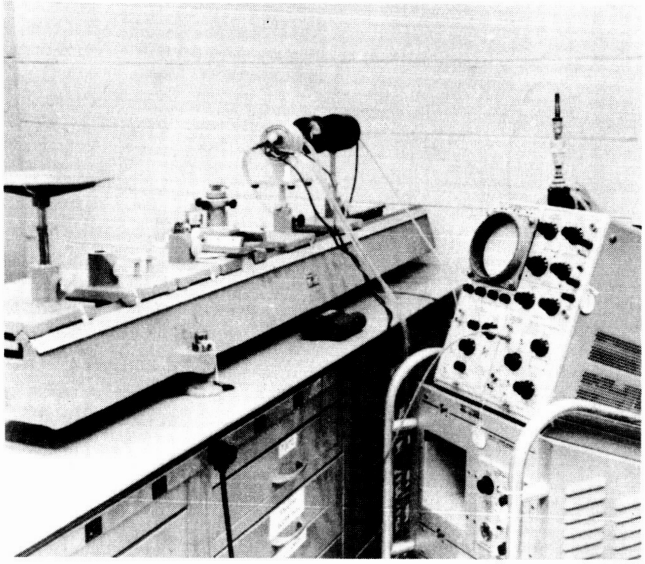

FIGURE 11. NEODYMIUM YAG CW LASER SYSTEM

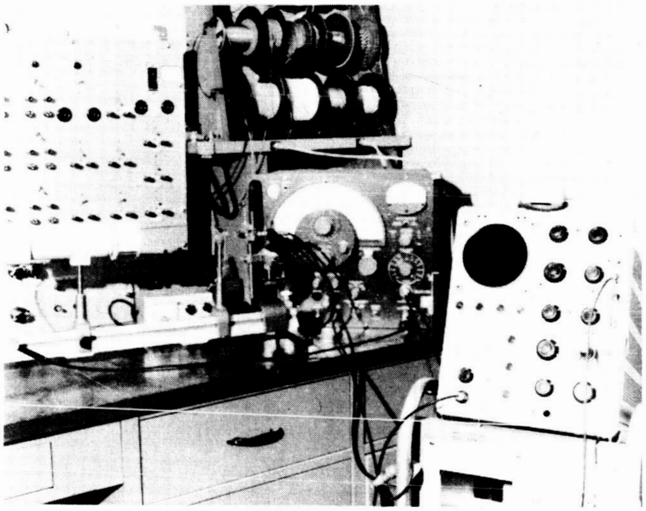

FIGURE 10. PHOTOMULTIPLIER TUBE CALIBRATION SYSTEM

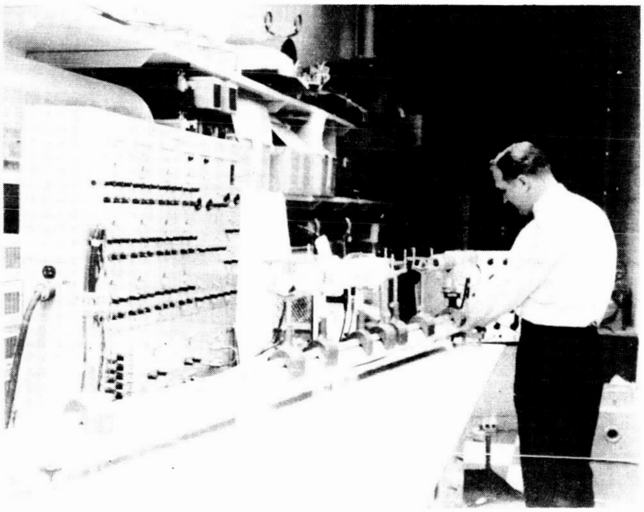

FIGURE 12. LASER BEAM STEERER AND EQUIPMENT

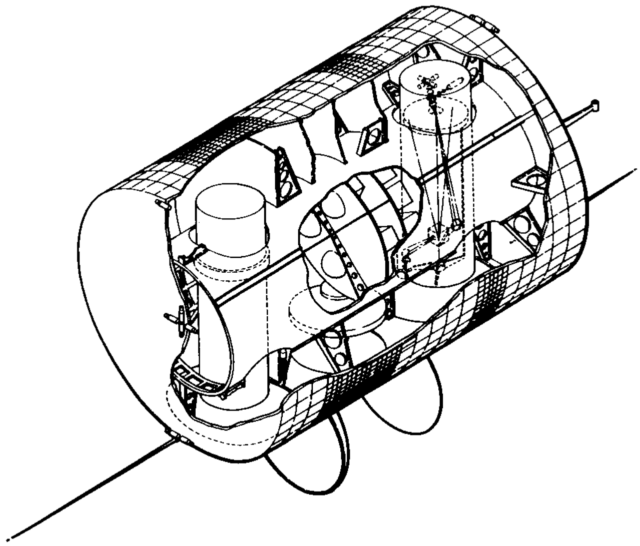

FIGURE 13. OPTICAL TECHNOLOGY SATELLITE

	kg
STRUCTURE AND SKIN	839.16
SOLAR CELLS AND BATTERIES	272.16
AUTOPILOT AND GUIDANCE	45.36
INERTIA WHEELS AND CONTROL	226.80
PULSED JET FUEL TANKS	226.80
MICROWAVE PACKAGE WITH ANTENNA	45.36
PULSED JET MOTORS, PLUMBING, AND CONTROLS	45.36
CABLING	45.36
THERMAL CONTROL	79.38
CONTROL COMPUTER	6.80
SOLAR SENSOR SUBSYSTEM AND COARSE ACQUISITION MECHANISM	6.49
TELESCOPE 1	295.20
TELESCOPE 2	360.97
DC TO AC INVERTERS	9.07
TELESCOPE 1 SUN SHIELD DRIVE ASSEMBLY	6.80
TELESCOPE 2 SUN SHIELD DRIVE ASSEMBLY	6.80
TOTAL	2,517.87
ADD APPROXIMATELY 10% FOR UNIDENTIFIED MISCELLANEOUS ITEMS	226.80
SATELLITE WEIGHT	2,744.67

FIGURE 14. PRELIMINARY WEIGHT ESTIMATE FOR THE OPTICAL TECHNOLOGY EXPERIMENTS SATELLITE AND MAJOR SUBSYSTEMS

MODE OF OPERATION	AVERAGE POWER CONSUMPTION (WATTS) SATELLITE WITH TELESCOPE NO. 1	SATELLITE WITH TELESCOPE NO. 2
QUIESCENT	15	15
ACQUISITION	300	370
TRACKING	260	330
COMMUNICATIONS	370	460

FIGURE 15. PRELIMINARY POWER CONSUMPTION ESTIMATE FOR THE OPTICAL TECHNOLOGY SATELLITE IN MAJOR OPERATIONAL MODES

LASER SYSTEMS RESEARCH AT MARSHALL SPACE FLIGHT CENTER N66-23458

By

Charles L. Wyman

SUMMARY

Laser systems research and development at MSFC have been concerned with communication, guidance, and tracking applications. This report describes two laser radar systems which are at an advanced stage of development. One is an airborne optical guidance system for rendezvous maneuvers and the other is a ground-based precision optical tracking system for advanced launch vehicles.

In advances beyond this breadboard development, work is being done on room-temperature continuous injection lasers, image dissectors and beam steerers, an optical superheterodyne receiver, a precision gas-bearing tracking mount, and other instruments and techniques.

Advantages that are expected to result from the research and development program are a reduction in system size and power requirements, elimination of problems associated with microwave techniques (e.g., ground clutter and backscatter), greatly increased operation range, and very high accuracy in tracking and ranging.

I. INTRODUCTION

The Marshall Space Flight Center is pursuing a laser systems research and development program directed primarily toward applications for guidance, tracking, and communications. Such systems are important to the national space program for a variety of reasons. Most of these reasons are based on two fundamental characteristics of laser beams: first, lasers are highly directional and, second, optical beams can carry tremendous information bandwidths.

By judicious application of these characteristics and by appropriate use of systems, the following potentials for laser systems can be seen.

1. Communicating at interplanetary distances with television bandwidths using systems of reasonable size and power.

2. Tracking objects, expecially cooperative ones, with unprecedented accuracy.

3. Developing guidance, tracking, and communications systems, for use in space, that are smaller, more accurate, and use less power than comparable systems using conventional techniques.

Several systems concepts are being investigated. Two systems in the advanced development stage are discussed in detail. These are the optical guidance system for rendezvous and the precision optical tracking system for advanced launch vehicles. Communications and tracking systems for deep space are being investigated under the optical technology satellite program. This work is in a preliminary study phase and is not discussed in this report.

The optical guidance system and the optical tracking system are both laser radars. The former is for spaceborne application and the latter is ground based. Certain techniques are common to both; consequently, similarities will be noted. However, the requirements and the overall systems are very different.

As an aid to the discussion of the two systems, the directional characteristics of lasers are briefly discussed and basic range equations are presented.

II. LASER BEAM DIRECTIVITY AND BASIC RANGE EQUATIONS

The diffraction of coherent electromagnetic radiation by a circular aperture causes an angular distribution of the energy for which, from the maximum intensity of the beam to the first minima, the beamwidth θ can be expressed as:

$$\theta = \frac{1.22\ \lambda}{D} .$$

θ = beamwidth
λ = wavelength
D = aperture diameter.

To a close approximation, the half power beamwidth θ_{hp} is expressed as:

$$\theta_{hp} = \frac{\lambda}{D} \quad .$$

For optical wavelengths the beamwidths are thousands of times smaller than the beamwidths for radio frequencies.

If the aperture is regarded as an antenna of area A_t, the gain or directivity D_t is expressed as:

$$D_t = \frac{4\pi A_t}{\lambda^2} \quad .$$

When equation 2 is substituted in equation 3, the expression for D_t is simplified to:

$$D_t = \frac{\pi^2}{\theta^2_{hp}} \quad .$$

A transmitter with directivity D_t illuminates a target at range R with a power density P_{dt} expressed by the equation:

$$P_{dt} = \frac{P_t D_t}{4\pi R^2} = \frac{P_t \pi}{4\theta^2_{hp} R^2} \quad .$$

A straightforward calculation will indicate that a laser transmitter will illuminate a target with an intensity millions of times greater than a radio frequency source of equal power and antenna size.

A complete development of range equations for the precision optical tracker is given in Reference 1. Range equations and signal-to-noise analyses for the optical guidance system are given in Reference 2.

III. OPTICAL GUIDANCE SYSTEM FOR RENDEZVOUS

This system is the result of a research and development program for the Office of Advanced Research and Technology (OART) to investigate the feasibility of using optical and laser techniques to generate guidance information during rendezvous maneuvers. The study has resulted in the development of a breadboard optical guidance system which is being evaluated at MSFC. The breadboard development has clearly established the feasibility and practicality of the project and is being followed up by development of a complete miniaturized prototype system for performance testing in aircraft or on a rendezvous simulator. Table I lists characteristics of the breadboard model and the miniaturized prototype.

TABLE I. OPTICAL GUIDANCE SYSTEM

Breadboard			
Parameters	Long Range above 3 km	Intermediate Range 3 km to 100 m	Short Range 100 m to 0
Acquisition range	14 km		
Acquisition angle	10°		
Range accuracy	± 0.5% of measured range	+0.5%	+0.1 m
Range rate	120 m/s	50 to 0.3 m/s	50 to 0.3 m/s
Range rate accuracy	+0.2%	+0.3 m/s	+0.03 m/s
Angular accuracy	+0.1°	+0.1°	+0.1°
Angular rate accuracy	+0.5 m rad/s	+0.05 m rad/s	+0.05 m rad/s
Test Prototype			
Acquisition range	50 km minimum		
Other parameters identical to breadboard system			
Prototype weight	less than 22.7 kg		
Power consumption	less than 50 watts		
Receiver telescope	16 cm aperture, 35 cm long, coaxial with acquisition telescope		
Mounting	tracking pedestal for simulation of automatic angular tracking		

The basic system configuration is depicted by the block diagram of Figure 1. An image dissector tube and a telescope are used for angular acquisition and tracking. The image dissector is a photomultiplier in which an internal aperture is used to limit the active area of the photocathode. By means of electrostatic focusing and magnetic deflection of the electrons emitted from the photocathode, the active area can be made to scan across the face of the tube. Thus, because there is a quadrature magnetic field, the small instantaneous field of view of the system can be scanned over a larger total field of view to generate angular information for acquisition and tracking purposes. Acquisition is performed as indicated in Figures 2 and 3. The target beacon and the long-range source on the chaser are thermoelectrically cooled pulsed gallium arsenide lasers. The laser on the chaser also supplies coarse-range information by measuring the time delay of the pulse reflected by corner reflectors on the target vehicle. The long-range system is indicated by the block diagram of Figure 4. Fine-range resolution is determined from three kilometers to docking, with a second ranging system consisting of an incoherent-light-emitting diode modulated continuously at 4.88 MHz. Both range systems use phase lock techniques to enhance signal-to-noise ratio. The short-range system is shown in Figure 5.

Figures 6 and 7 show the breadboard system. The chaser vehicle transceiver for the prototype system has been miniaturized to the configuration shown in Figure 8. The prototype electronics use microcircuitry and will occupy less than 1/30 cubic meter.

The concept depicted in Figure 9, a logical extension of this prototype system, utilizes room-temperature continuous injection lasers for a simplified and more accurate ranging system.* It also uses laser beam steerers; these eliminate the necessity of controlling the attitude of the spacecraft or of gimbaling the telescopes. The beam steerers are under development and are being designed into an acquisition system for the precision optical tracker. Room-temperature continuous injection lasers are also under development and are expected to be operational in a year or two. As the lasers become more powerful and efficient, the size of the optical guidance system shrinks because smaller telescopes are required. In the concept of Figure 9, only one telescope and one detector are used on each vehicle. Less than one watt of continuous power from the laser is required to extend the range of this system to over 100 km with an acquisition angle of 30 degrees. Furthermore, with one watt available, the telescope collector would be only 7 cm in diameter and the telescope and detector package would be less than 15 cm long.

IV. PRECISION OPTICAL TRACKING SYSTEM FOR ADVANCED LAUNCH VEHICLES

Laser radar systems have the potential of tracking objects to an unprecedented degree of accuracy. Areas in which precision tracking information is of interest to NASA are as follows:

1. Tracking advanced launch vehicles.
2. Tracking reentry vehicles.
3. Tracking satellites.
4. Tracking deep-space probes for communications purposes and position information.

With these applications in mind, an experimental and developmental program was undertaken for OART to develop and evaluate various acquisition, tracking, and ranging techniques with lasers. The results of the program ultimately will apply to specification of optimum techniques and systems configurations for various tracking problems.

Early in the project, it was determined that the best results could be obtained by choosing one particular tracking problem and developing an experimental prototype that could be used for testing under realistic conditions. Tracking advanced launch vehicles was chosen because it has many characteristics similar to other possible systems and is an area in which the parameters are well known. Furthermore, some requirements for tracking the vehicle during the early launch phase have never been fulfilled. For example, when microwave radar systems operate near the horizon during the early launch phase, they are useless because of ground clutter and backscatter problems. In addition, photographic and television techniques do not have range measuring capability and lack in angular resolution.

Consequently, development of a precision optical tracking system for advanced launch vehicles is well under way. Reference 1 has a discussion of the general system philosophy and several preliminary analyses and studies including error analysis, trajectory analysis, range analysis, refractive and turbulence effects of the earth's atmosphere, and servo analysis.

Table 2 lists characteristics and parameters of the system, which is being designed and assembled in-house. There is work under contract for developing a precision gas-bearing tracking mount and for fabricating a tracking and acquisition subsystem that utilizes image dissectors and beam steerers. Figure 10 is a simplified block diagram of the system.

TABLE II. PRECISION OPTICAL TRACKING SYSTEM*

Early Launch Phase Tracking Requirements				
Flight Interval (Seconds)	Data Required	Reduced Data Accuracy		
		Class I	Class II	Class III
0 to 5	position	0.5 m	0.1 m	0.1 m
	velocity	1.0 m/s	0.1 m/s	0.1 m/s
	acceleration	0.2 m/s^2	0.5 m/s^2	0.01 m/s^2
5 to 25	position	5.0 m	1.0 m	1.0 m
	velocity	1.0 m/s	0.1 m/s	0.1 m/s
	acceleration	0.5 m/s^2	0.1 m/s^2	0.02 m/s^2
25 to 50	position	30 m	10 m	5 m
	velocity	1.0 m/s	0.2 m/s	0.1 m/s
	acceleration	0.5 m/s^2	0.1 m/s^2	0.02 m/s^2

System Parameters	
Angular resolution	1.25 arc sec
Angular accuracy	5.0 arc sec
Range resolution	1 cm
Maximum range accuracy	5 to 10 cm
Acquisition field of view	0.25°
Tracking field of view	30 to 90 arc sec
Maximum range	10 km
Maximum range rate	200 m/s
Maximum angular rate	5°/s
Maximum angular acceleration	1°/s^2
Telescope collector aperture	15 cm
Transmitted laser power	50 mW
Beam divergence	30 to 90 arc sec

* This is an experimental system to be used to evaluate laser tracking and ranging techniques.

Techniques that will be evaluated but which are not indicated in the diagram include:

1. Measurement of the radial component of velocity by optical superheterodyne techniques.

2. Measurement of angular velocity information of the tracking mount, using ring lasers.

* Pulsed room-temperature injection lasers are available from several sources. One order of magnitude decrease in threshold of these lasers will allow continuous wave operation. Several materials show promise of continuous wave operation. Research contracts with IBM, RCA, and Tyco Laboratories are directed toward eventual continuous wave room-temperature operation.

Much work has been done at MSFC on optical superheterodyne techniques (Ref. 3). In addition, there is work under contract for the development of an optical superheterodyne receiver.

V. CONCLUSIONS

The two developmental models of the optical guidance system will demonstrate the practicality of using laser and optical techniques for space guidance problems. Future models will use essentially the same ranging and tracking techniques but will become smaller and operate over longer ranges as better laser sources become available. Furthermore, use of other optical techniques such as laser beam steerers will result in very advantageous systems configurations for which there are no microwave counterparts.

The optical tracking system being developed will be a versatile research tool in experimentation and investigations leading to design data for optimum optical tracking and ranging systems. Moreover, the system will perform with accuracies unobtainable in the past.

The useful application of lasers has required much work in the development of associated technologies including devices, components, and techniques. Much more work is required in these areas and in the development of the systems themselves. However, the usefulness of lasers for application in the space program is established, and practical systems are beginning to appear.

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2. Optical Guidance Feasibility Study - Quarterly Reports and Summary Report. Contract NAS8-2661, Request No. TP-2-83-1469-S1; Data Corporation, Dayton, Ohio, March 1965.

3. Lee, C.: An Investigation of Photoelectrically Heterodyning Coherent Light. Astrionics Research and Development Report No. 2, NASA TM X-53044, May 1, 1964.

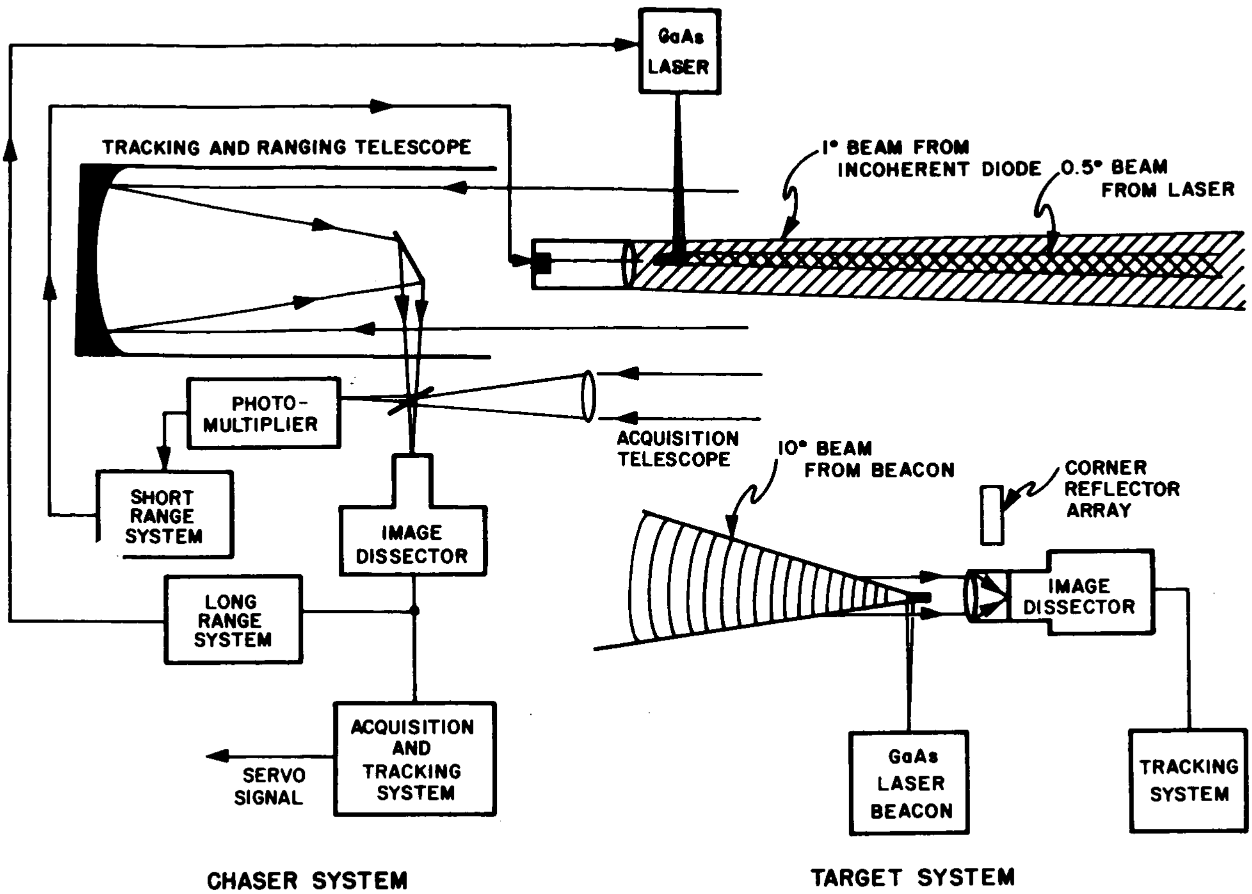

FIGURE 1. OPTICAL GUIDANCE SYSTEM

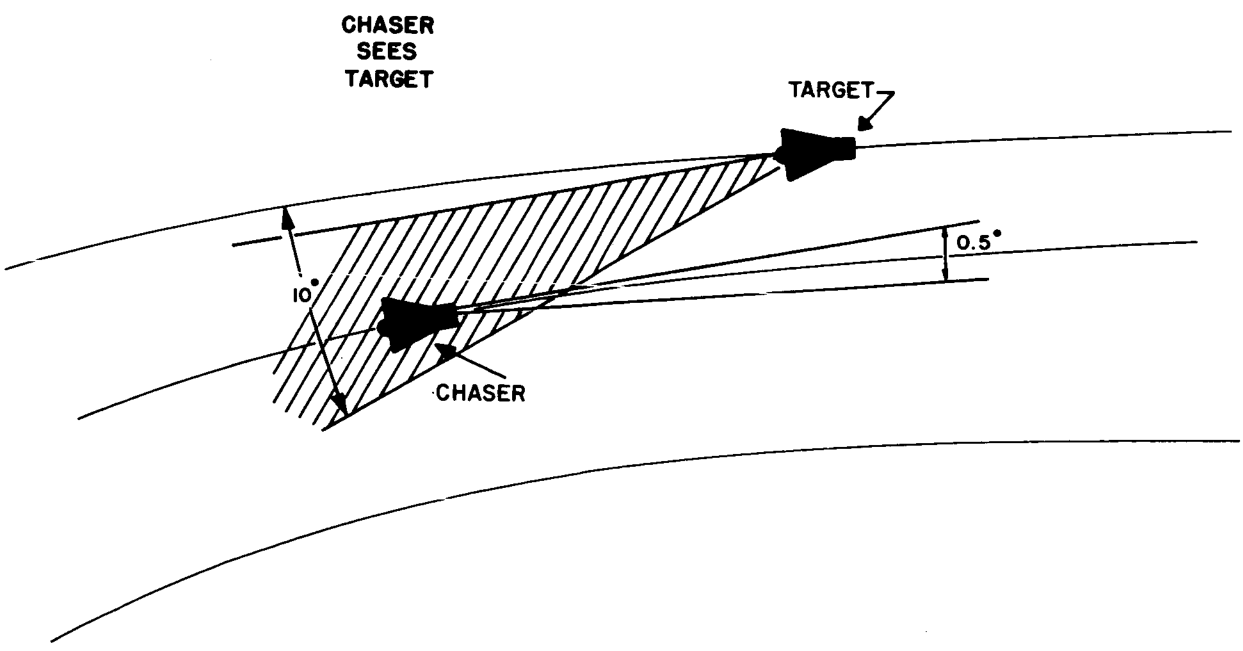

FIGURE 2. PHASE I OF ACQUISITION

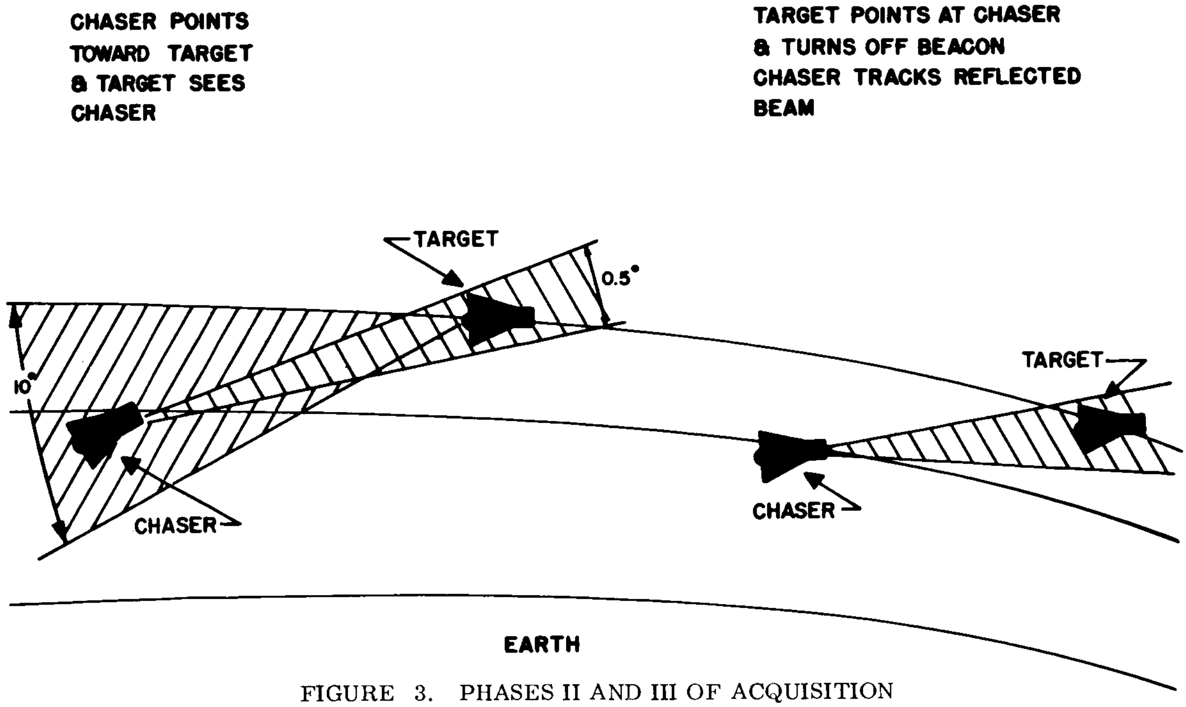

FIGURE 3. PHASES II AND III OF ACQUISITION

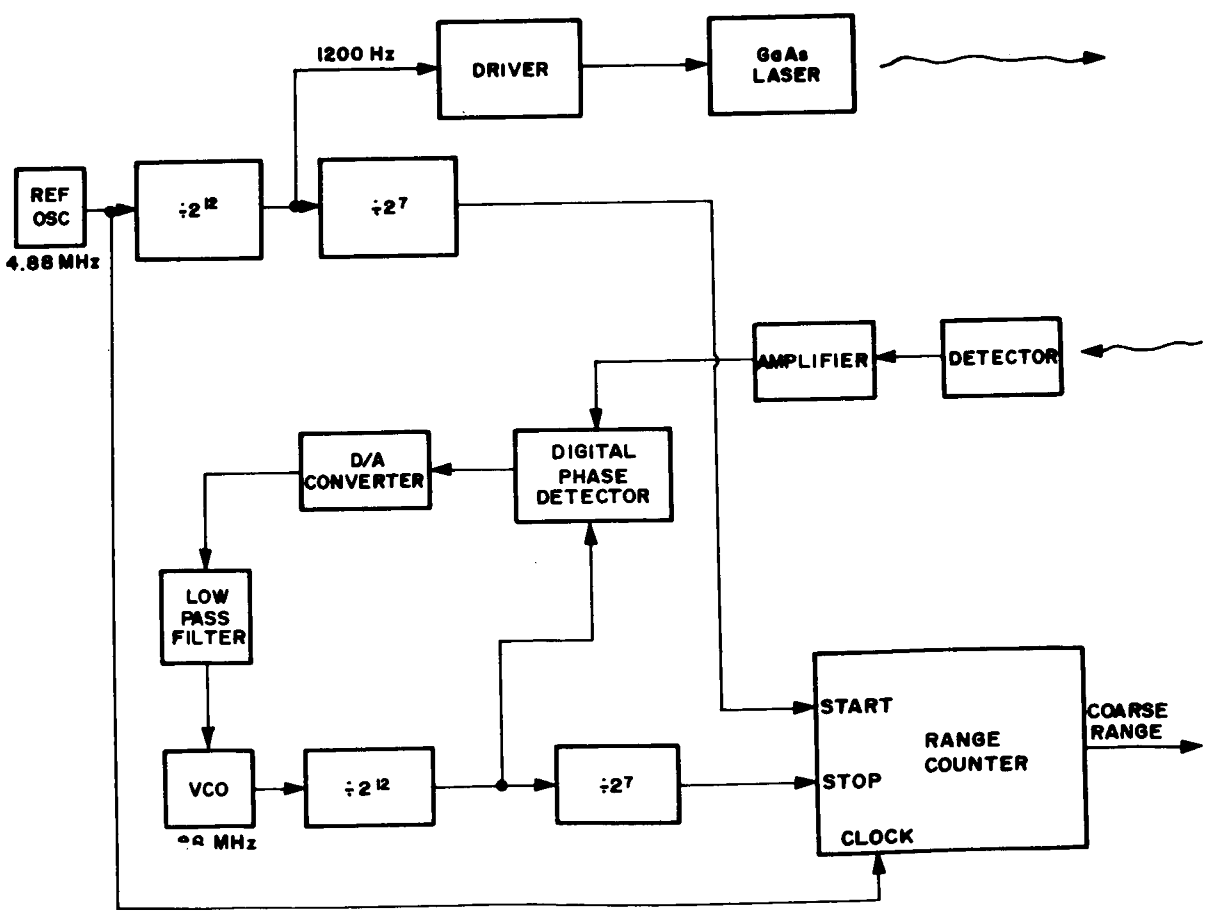

FIGURE 4. LONG-RANGE SYSTEM

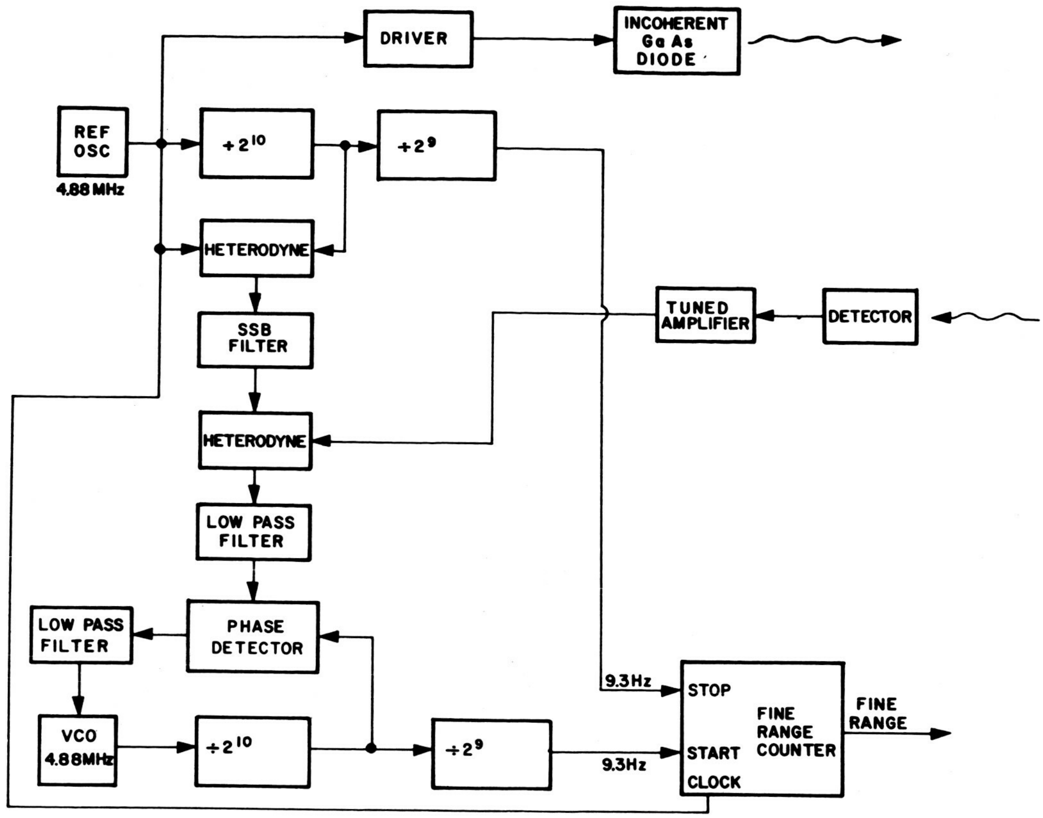

FIGURE 5. SHORT-RANGE SYSTEM

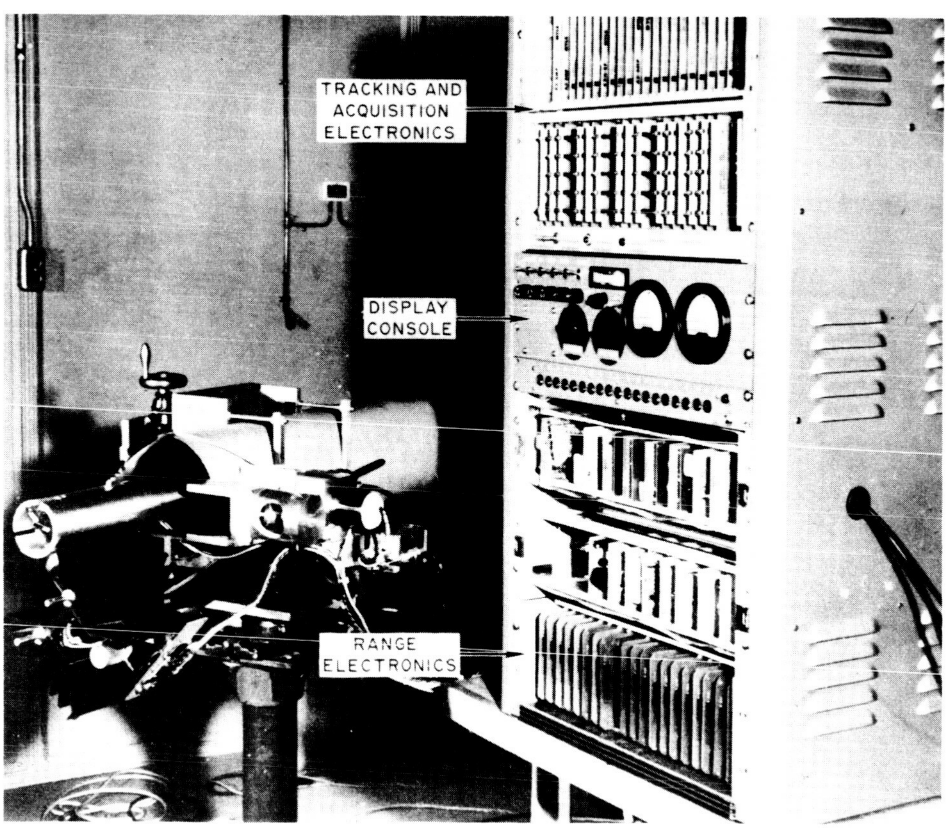

FIGURE 6. BREADBOARD SYSTEM, OVERALL VIEW

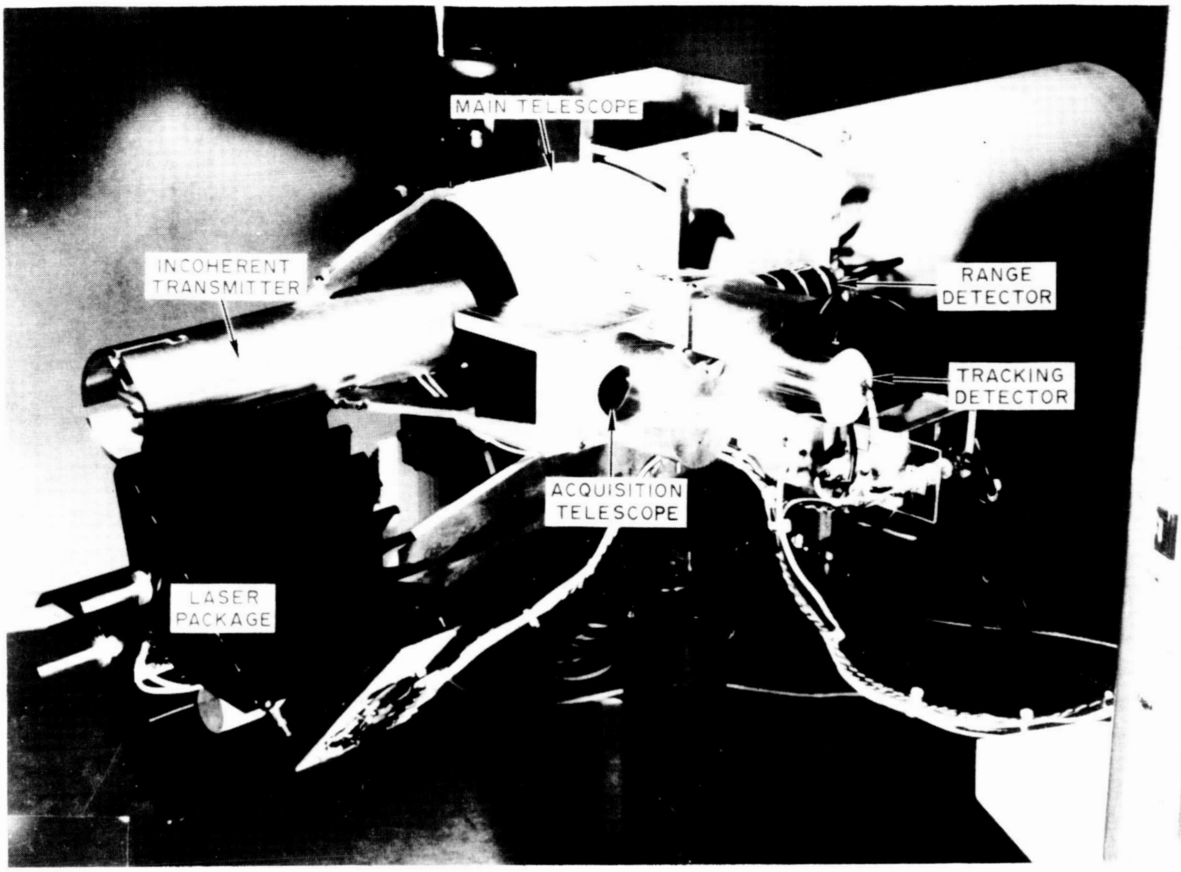

FIGURE 7. BREADBOARD SYSTEM, ACQUISITION AND DETECTION COMPONENTS

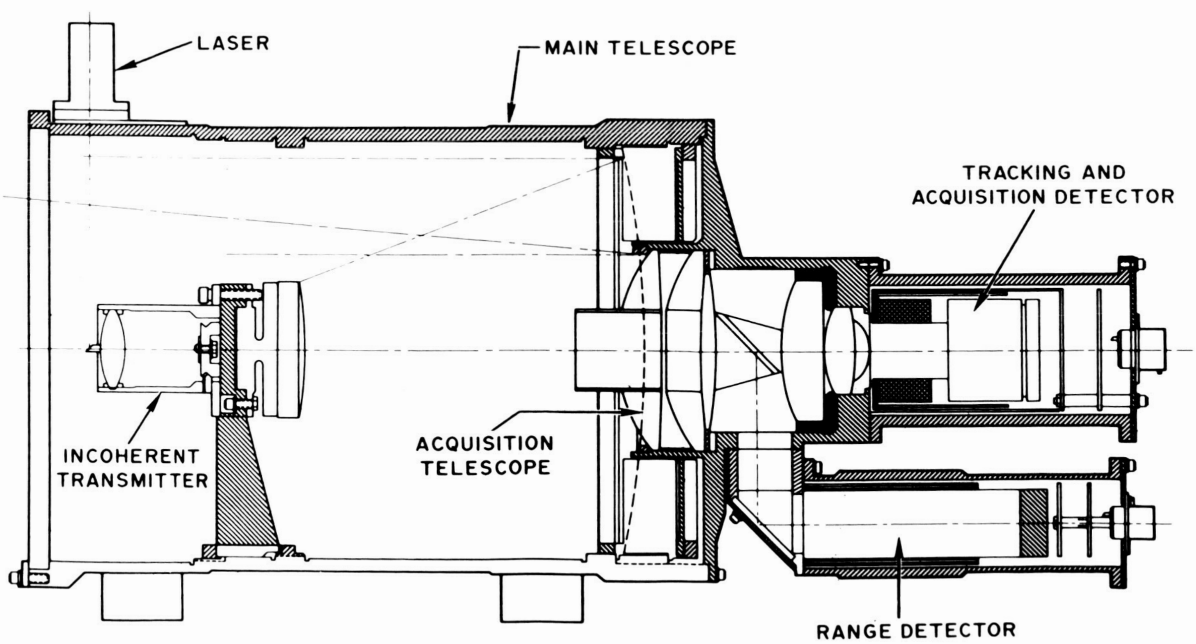

FIGURE 8. PROTOTYPE OPTICAL GUIDANCE SYSTEM TELESCOPE

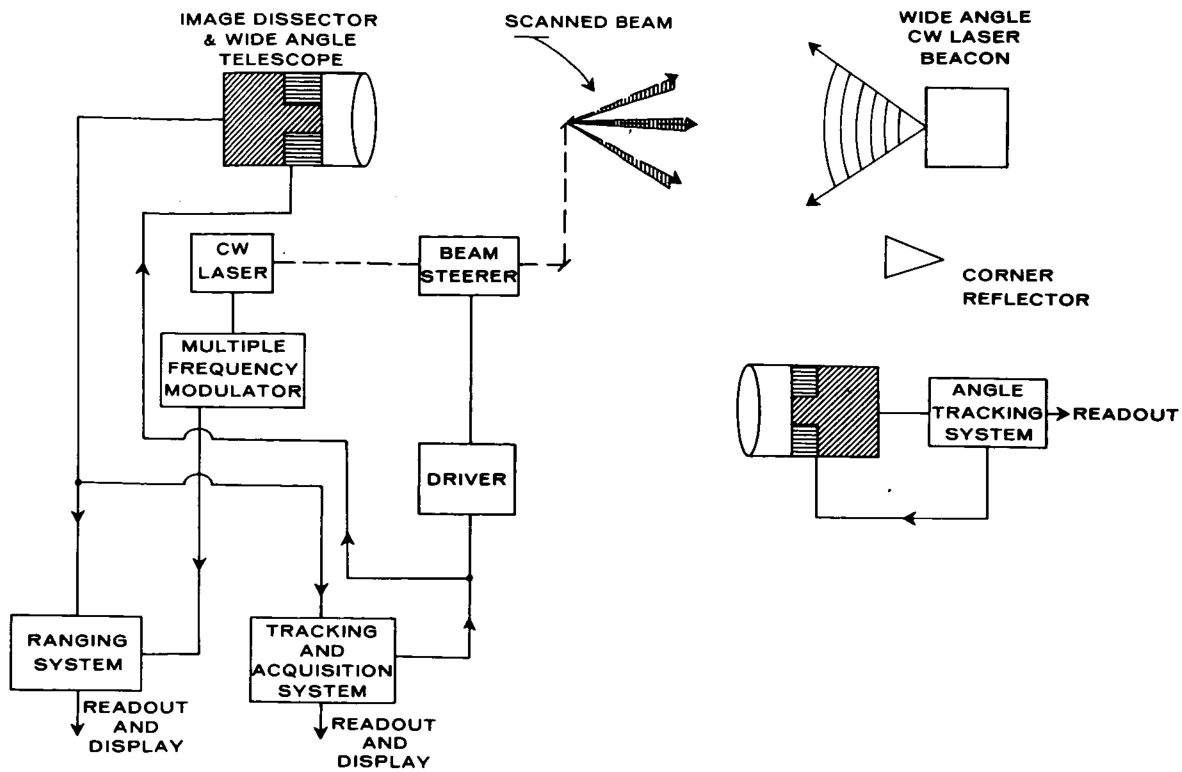

FIGURE 9. OPTICAL GUIDANCE SYSTEM OF THE FUTURE

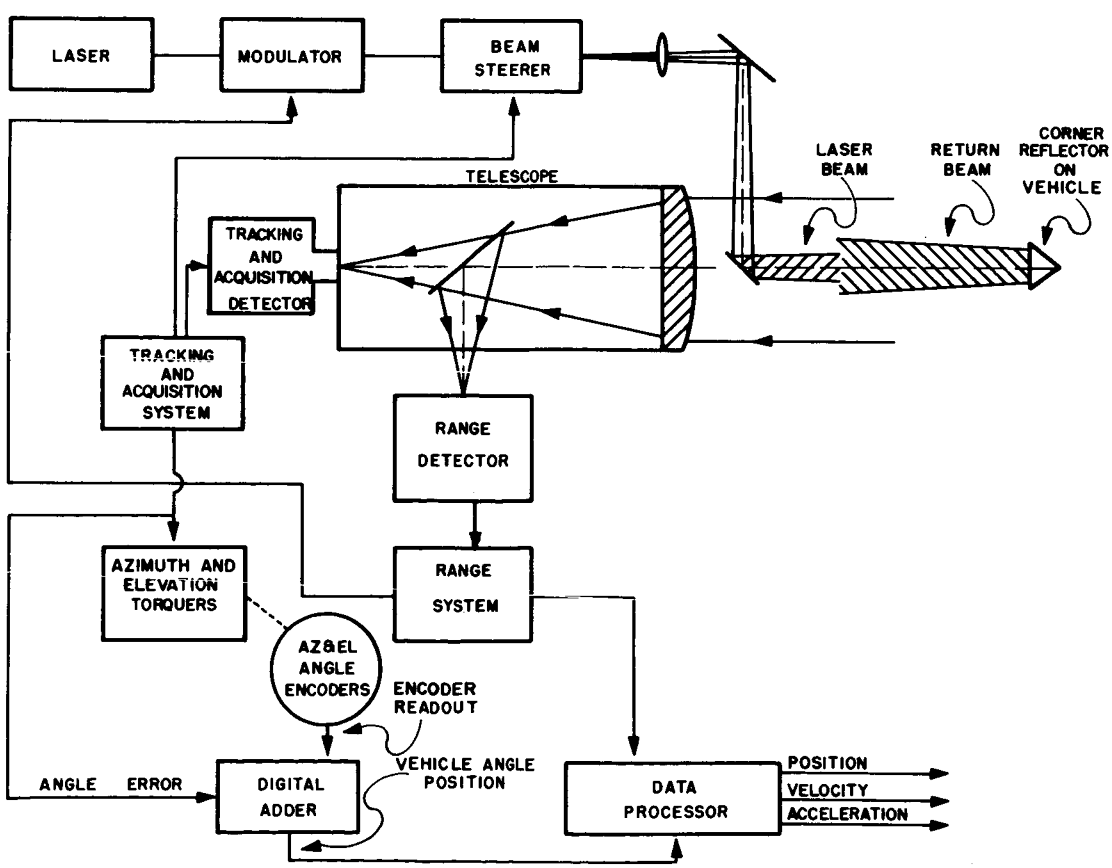

FIGURE 10. SIMPLIFIED DIAGRAM OF PRECISION OPTICAL TRACKER

this branch and several interesting and unique projects are currently progressing. Among these are a differential amplifier and a 100-ampere transistor. The former requires an extensive knowledge of integrated circuit design and fabrication, and work on it is being used to gain experience in these areas as well as to demonstrate in-house capability. The latter advances the state of the art in that a device of this rating requires a complete silicon wafer. In effect, this means 100-percent yield on any single wafer. Admittedly this is an ambitious undertaking for the laboratory, but the effort is expected to be successful.

The integrated-circuit fabrication laboratory has the capability for wafer preparation; transferring photographic masks using an in-house-built nine-element fly's eye camera; applying photo resist; and selective etching, oxidizing, diffusing, metalizing, and packaging. Chemical sinks and laminar-flow clean benches are strategically located throughout the clean rooms.

A diagnostic facility complements the fabrication laboratory. X-ray and infrared techniques are used for device-failure analysis, and interferometric methods are used to determine oxide thicknesses, junction depths, and diffusion profiles. An electron-beam-scanning microscope is now being installed.

An evaluation console for study of electrical characteristics of in-house and commercially made devices has been developed, and device parameters can be obtained quickly.

The Pilot Manufacturing Branch of Astrionics Laboratory has had a microelectronics thin-film laboratory for several years. The primary functions of this facility are to provide experimental thin-film circuits to equipment designers and to study improved deposition processes using sputtering and evaporation in a vacuum. The fabrication of passive devices is currently under good control, and much research has been directed toward the development of thin-film active devices.

Another capability of this laboratory is the welding and interconnecting of discrete active devices with thin-film leads, resistors, and capacitors to form hybrid circuits and systems.

A laboratory for the fabrication and analysis of thin magnetic films is a recent addition to the Applied Research Branch of Astrionics Laboratory. Equipment presently being set up will make it possible to deposit thin magnetic films of differing compositions and to study the basic magnetic properties of these films through a Kerr magneto-optic system.

The application of thin-film magnetic memories in computer circuits has been under continual development. The discrete activity indicator and the nondestructive readout buffer are recent achievements of this laboratory. The former acts as auxiliary equipment freeing the computer of many tasks, thus speeding up its data-handling ability. The latter utilizes single rather than multiaperture cores and has been demonstrated to be faster, less complex, and more efficient than the nondestructive readout buffers constructed with multiaperture cores.

An additional but very important function of all these in-house facilities is their use for more effective monitoring of contracts with industry which deal with the development of devices and with phenomenological studies.

III. RESEARCH AND DEVELOPMENT BY CONTRACT

A contract with Research Triangle Institute for the mathematical modeling of the diffusion process in the fabrication of integrated circuits has recently been extended. A good model relating diffusion time, temperature, impurity flow, and background concentration to junction depth and sheet resistance has been developed for the phosphine gas diffusion method. Remaining to be found is a relation between these original parameters and electrical characteristics of devices such as reverse current and breakdown voltage of p-n junctions. Investigations indicate that diffusion tube history and surface phenomena must be taken into account to achieve this. This contract cost was $38,000.

A final report will be forthcoming shortly from Texas Instruments, Inc., describing the effect of epitaxial parameters on the reliability of silicon planar devices. Five parameters important in epitaxial growth are considered: carrier concentration, carrier mobility, carrier lifetime, position of p-n junctions, and the concentration of metal precipitates. Analysis involves eight process variables: dislocation density of substrates, substrate resistivity, depth of damage, surface cleanliness, dopant, deposition rate and temperature, and $SiCl_4$ concentration. Transistors were fabricated and step stressed to accumulate reliability data. These results were then correlated with failure analyses. The contract cost was $74,000.

MICROELECTRONICS PROGRAM AT MARSHALL SPACE FLIGHT CENTER

N66-23459

By

James C. Taylor

SUMMARY

The purpose of the microelectronics program at MSFC is to convert the electronics equipment of the Saturn launch vehicle to microcircuits. The result will be a reduction in size and weight of components and systems, and an increase in their life and reliability. The diverse work constituting this program is described under in-house and contract research and development, contract microcircuit development, and conversion of Saturn equipment.

In-house research and development cover a wide range of tasks in microcomponent fabrication processes and techniques and in diagnostic analysis and evaluation.

Contract research and development, much of which complements in-house work, includes studies on thin magnetic films, crystal defects, oxidizing methods for low-temperature deposition of oxide films, fast-scan infrared detection, and manufacturing requirements and problems related to microminiaturization and circuit reliability.

Examples of microcircuit development under contract are an integrated-circuit amplifier resistant to irradiation and operable under high temperatures; an integrated-circuit oscillator/amplifier with three levels of power operation; a 100-ampere transistor intended to replace heavy-duty relays; and a 10-ampere transistor with a 50-percent duty cycle, for use in laser modulation. Other contracts deal with performance capabilities of specific integrated circuits, the establishment of a standard for multilayer printed circuit boards, and nondestructive qualitative testing of through-hole connections in such boards.

In the program of Saturn equipment conversion, the study and development of the following are described: an integrated assembly for a 75 VA static inverter; stabilizing circuits; unit logic devices; and other miniaturized circuits and assemblies such as a switch selector with built-in redundancy, a control signal processor, a radar altimeter, and a control computer.

I. INTRODUCTION

A program is in progress at Marshall Space Flight Center to convert the electronic equipment of the Saturn launch vehicle to microcircuits. Although the work has been under way for several years, a concerted drive was started approximately two years ago to accomplish the goal as rapidly as possible.

There are many advantages in the use of microcircuits in launch vehicle systems; the most important one is that of higher reliability. This, in turn, allows a higher degree of complexity and makes more sophisticated systems possible. Test results indicate that various types of microcircuits are more reliable than those made with discrete components; but it is the all-diffused monolithic circuit that is in widest use and on which the bulk of reliability testing has been done. The policy at MSFC is to use all-diffused circuits where they meet performance requirements and to use thin-film circuits and hybrids in special applications.

The program to convert the Saturn electronic equipment to microcircuits is extensive, and there is a high degree of cooperation between various in-house laboratories and the semiconductor industry. Virtually all major components of the electronic system are now under study to determine the possibility of using microcircuits. The redesign of the equipment is backed by in-house laboratories doing research in semiconductor and thin-film materials technology. The program is separated into the following areas: in-house research and development, research and development by contract, microcircuit development by contract, and Saturn equipment conversion.

II. IN-HOUSE RESEARCH AND DEVELOPMENT

The various processes and techniques involved in the forming of semiconductors and integrated circuits are continually being studied in the Applied Research Branch of Astrionics Laboratory. Complete facilities for fabricating these devices are now available within

Westinghouse Electric Corp. is completing a study of the effect of crystal defects on the reliability of epitaxial planar devices ; a final report will be issued soon. The effort involved initially a literature survey of pertinent research on the occurrence, causes, and detection of silicon crystal defects and their effect on device reliability and failure mechanisms. A continuation of this study by Westinghouse has concentrated on large area epitaxial devices as a complement to the 100-ampere transistor development, and the result is a higher level of confidence for that program. Large aggregates of foreign particles found in bulk silicon can be detrimental to junction characteristics. These aggregates are predominantly gold phosphide and may be as large as a half micron on a side. Other aggregates include silicon phosphide, silicon nitride, and silicon carbide. These aggregates serve as a starting point for stacking faults which appear during epitaxial growth. A significant recommendation emerging from this contract is to use argon rather than nitrogen as a carrier gas and to use pure HCl as an etchant, followed by dilute steam. The cost of the contract was $ 120, 000.

A contract with Westinghouse for the determination of manufacturing problems that significantly affect the reliability of silicon planar devices is nearly complete. This $ 54, 000 contract has involved a literature survey of pertinent research in the field to determine the problems associated with yield and reliability. Both materials and fabrication processes were considered.

A contract presently exists with the Georgia Institute of Technology for the investigation of thin magnetic films for memory applications. Films of various magnetic alloys were prepared by several deposition processes and the resultant films were evaluated for magnetic properties. A literature survey of research pertinent to the field was made. This $ 15, 000 contract included a determination of the relationship between the variables of preparation, composition, impurity content, degree of oxidation, amount of occluded gas, and magnetic properties (saturation flux, coercive force, saturation induction, remanence, squareness, and anisotropy constant).

A study of interactions of magnetic materials using coupled films with a closed flux geometry is being made by Honeywell, Inc. This $ 50, 000 contract is an effort to develop higher density magnetic-film memories. It will involve the fabrication of samples having closed flux paths and the evaluation of these samples for magnetic coupling characteristics to provide a better analytical understanding of the interactions. A complete analysis of the interlayer material will be included. Finally, models explaining the coupling mechanism will be proposed.

A contract with Motorola Semiconductor Products, Inc. , calls for the study of metal-oxide semiconductor (MOS) systems to increase reliability of silicon integrated circuits. Part of this effort was a literature survey of pertinent MOS research. The many fabrication steps from crystal growing through the various processes will be described and evaluated as related to reliability. Appropriate tests both during processing and on the finished devices to relate materials and process parameters to characteristics and failure rate will be proposed. This will include environmental as well as electrical stress testing. A sum of $ 46, 000 is being funded for this study.

A contract with the University of Texas provides for the study of silicon/silicon-oxide interfaces. Different oxidizing techniques will be studied with regard to inversion layers to improve the reliability of solid-state devices made from silicon. Determination will be made of the chemical purity of the silicon, its physical perfection, surface smoothness and cleanliness, method of growing oxide film, and type of electrical contact. Possible solutions to problems arising from surface phenomena will be recommended. The funding for this study was $ 34, 000.

A contract with Westinghouse calls for research on the growth and deposition of low-temperature oxide films on silicon. Two oxidation methods will be developed. One will be anodic and the other will involve sputtering. MOS devices will be fabricated by using these two oxidizing methods, and they will be compared with MOS devices fabricated by normal high-temperature oxidizing techniques. Both n- and p-channel devices are to be studied. A study also will be made to determine the effect of certain impurities in the oxide acting as gettering agents to improve the MOS stability. The funding for this work is $ 61, 000.

A contract with Raytheon Co. calls for the development of a fast-scan infrared detection system to be used to assess the reliability of semiconductor devices.

Martin Co. has a contract to establish the basic requirements and processes for the fabrication of microminiaturized multilayer printed circuit boards. The top and bottom layers shall be heat resistant to parallel gap welding temperatures. The contract cost is $ 30, 000.

Auburn University has a contract to determine the relationship of premature breakdown to the conditions of deposition in thin-film capacitors having dielectric thicknesses from 0. 1 to 2 microns. This contract, for $ 74, 000, is expected to improve the reliability of circuits incorporating thin-film capacitors.

A \$10,000 contract with Buckbee Mears, Inc., for performing chemical etching and electro-forming services in connection with the in-house thin-film program is current.

Burroughs Corp. has a contract to determine the role of magnetostriction in thin films, since a satisfactory characterization of this phenomenon has not been achieved. A number of possible mechanisms for the origin of magnetic anisotropy have been proposed, in which magnetostriction plays an important role, for example, directional ordering of atomic pairs, preferential impurity alignment, and atomic or lattice constraints. This is a study contract for approximately \$20,000.

Contracts are being considered for the following work:

a. A study of the factors affecting the reliability and the radiation resistance of MOS devices.

b. A study of disilicides for decreasing the saturation resistance of monolithics.

c. A determination of the status of ultrachemical analysis for semiconductor devices.

d. The development of a practical system for fabricating junctions and making interconnections by utilizing ion implantation techniques.

e. Control of inversion layers for better oxide stability in silicon devices.

f. The development of a ferromagnetic compensation memory, using optical accession.

g. The development of batch fabrication techniques for magnetic memories, to replace cores and to increase packing density.

h. The development of a family of compatible linear silicon integrated circuits.

i. The development of a short-term method to determine the reliability of silicon integrated circuits.

j. An investigation to improve evaporated thin-film resistors.

k. A study of the dielectric properties of materials for use in thin-film capacitors.

l. A study of various welding techniques in modular electronics.

IV. MICROCIRCUIT DEVELOPMENT BY CONTRACT

An integrated-circuit silicon carbide amplifier is being developed by Westinghouse to demonstrate the anticipated high-temperature operation and radiation resistance of such devices. A future satellite could carry a silicon carbide amplifier through the Van Allen belt, as a modest experiment.

Figure 1 shows an integrated-circuit power amplifier, currently in the final stages of development by Westinghouse. The two silicon chips each contain a transistor, a resistor, and a backup diode. Figure 2 is a schematic of the device. The amplifier is designed for use as the output stage of static inverters and other switching applications. It is intended for 400 Hz use and is fabricated by simultaneous diffusion techniques to achieve a thick base region, thus eliminating second breakdown as a problem. The amplifier will have a gain of 10 at 10 amperes collector current, and V_{ceo} will be better than 150 volts. The contract is for \$64,000.

A development in its initial stages at Westinghouse is an oscillator/amplifier (Fig. 3) which will be usable as either an oscillator or an amplifier. The package will be the same as the power amplifier shown in Figure 1, but will have additional leads. Three different levels of power operation will be possible, making this a very versatile integrated block. A standard circuit of this kind, when combined with a suitably designed toroidal transformer having a core with a rectangular hysteresis loop, will have many applications where isolation or nonstandard dc voltages are required. The maximum collector current will be 3 amperes at a gain of 30, and V_{ceo} will exceed 125 volts. A square wave of voltage is expected to be reproduced at a frequency of 50 kHz. The contract is for \$78,000.

Westinghouse currently is working on the development of a 100-ampere transistor utilizing an entire silicon wafer. Double epitaxial growth has been demonstrated recently, and this lends itself well to fabricating this device. Figure 4 shows a prototype. More recent work has shown that a smaller package should be possible. Figure 5 shows the appearance of the completed wafer. The base fingers radiate from the center, the emitter fingers extend toward the center, and the collector covers the entire back surface of the wafer. The breakdown voltage V_{ceo} for this device will be 150 volts and the switching speed will be 10 kHz. The application of this transistor as a replacement for heavy-duty relays and high-power switching is being considered. Funding for the development amounts to $149,000.

A 10-ampere transistor for use as a laser modulator is in the final developmental stages at the Bendix Corp. Achieving reliable electrical isolation from the case was a major problem in this work. The problem has been overcome and testing of devices will take place soon. The main feature of this transistor is that it will be capable of pulsing a gallium arsenide injection laser with a pulse having a total duration of 10 nanoseconds or less. The transistor has a 50-volt rating and will not be operated in the saturated mode. This device will have the further advantage over conventional systems of allowing a 50-percent duty cycle. Current systems involve charging a capacitor or delay line and then suddenly discharging through a controlled rectifier. This development substantially advances the state of the art. The contract is for $51,000.

Brown Engineering Co. has a $49,000 contract to study the performance capabilities of certain integrated circuits. The objectives of this program are to define the systems capabilities of the Texas Instrument series 51 and the Sylvania SUHL TTL digital monolithic silicon integrated circuits and to determine the electrical test specifications that guarantee operation within the defined system capabilities.

Under a $50,000 contract, IIT Research Institute is conducting a study of nondestructive testing for multilayer printed circuit boards. Procedures are being conceived primarily for qualitative testing of through-hole connections. Promising techniques seem to involve axial transverse laminography for coarse inspection to determine questionable areas and a probe of these areas for closer inspection.

A contract with Texas Instruments calls for the establishment of a standard for multilayer printed circuit boards through a development program. Funding for this is about $140,000.

V. SATURN EQUIPMENT CONVERSION

A $222,000 contract with Texas Instruments calls for the development of integrated assemblies for a 75 VA, three-phase, 400 Hz static inverter. The work is intended to produce an improved, highly reliable power supply for a gyro stabilized platform. Figure 6 is a block diagram of the assemblies to be fabricated in monolithic form. The crystal oscillator and binary countdown to bring the frequency from 2.4596 MHz to 4.8 kHz are shown in one block. The shift register to produce six 400 Hz outputs at intervals of 30 electrical degrees is shown in another block. There will be six monolithic output amplifiers and an integrated circuit feedback voltage regulator.

Dual contracts have been let with Bendix and Kearfott for the development of microelectronic circuits for stabilization of gas-bearing gyro servoloops. This is expected to result in higher reliability, longer operating life, and savings in space and weight for inertial guidance electronics. Specifically, the contracts call for three modules: preamplifier detector, active filter network, and driver amplifier, as shown in Figure 7. The contracts are presently in the initial design stage and the cost of each is $70,000 to $75,000.

A contract currently is being sought to provide a second source to supply unit logic devices (ULD's). These are to be compared with the ULD's produced by International Business Machines Corp. in the development of the guidance computer. Figure 8 shows one of the pages of the computer containing the ULD's. There are ten pages per computer. The contract is expected to amount to $100,000.

A contract with Fairchild Camera and Instrument Corp. calls for microminiaturizing the switch selector. It shall be shown that a design incorporating microelectronics elements including built-in redundancy is more reliable than the present version built of discrete components. The finished device will meet all requirements for flight application. The funding for this effort is $140,000. Figure 9 shows the microminiaturized version of the switch selector.

Westinghouse is developing a radar altimeter. Monolithic circuits are being used wherever possible to obtain the most reliable system. Where monolithics are not applicable, hybrid and thin-film techniques are employed, and conventional components when necessary. Figure 10 shows a block diagram of the altimeter, and Figure 11 shows a sketch of the proposed housing. Investigations to determine the feasibility of using radar-altimeter-type systems in surface studies of the earth, moon, and planets are continuing. The estimated cost of microminiaturizing the radar altimeter is $534,000.

The control signal processor serves as an interface between the control-rate gyros and the remainder of the system. There is a contract with Martin, for $253,000, to miniaturize this processor by reducing the weight, size, and power requirements, and to increase reliability through the use of integrated circuits, thin films, and miniaturized components.

A contract with Electronic Communications, Inc., calls for microminiaturizing the control computer. The objective is to design and fabricate two flight-qualified control computers using integrated circuits, thin films, or miniature components. This first phase involves design and the study of the best direction to take in accomplishing this task. Major goals are increased reliability, reduced size and weight, and lower power requirements. The first phase of this program will cost $130,000.

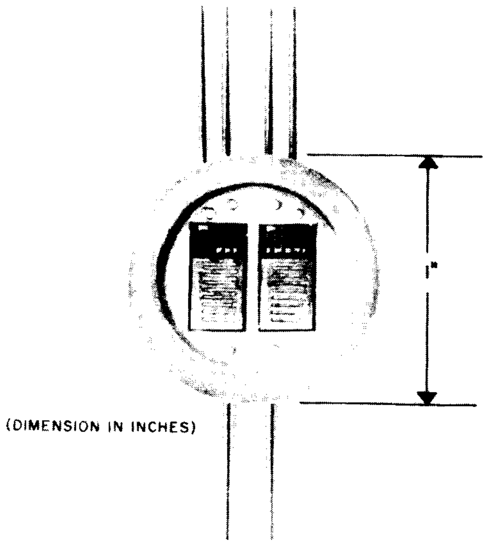

FIGURE 1. INTEGRATED-CIRCUIT POWER AMPLIFIER

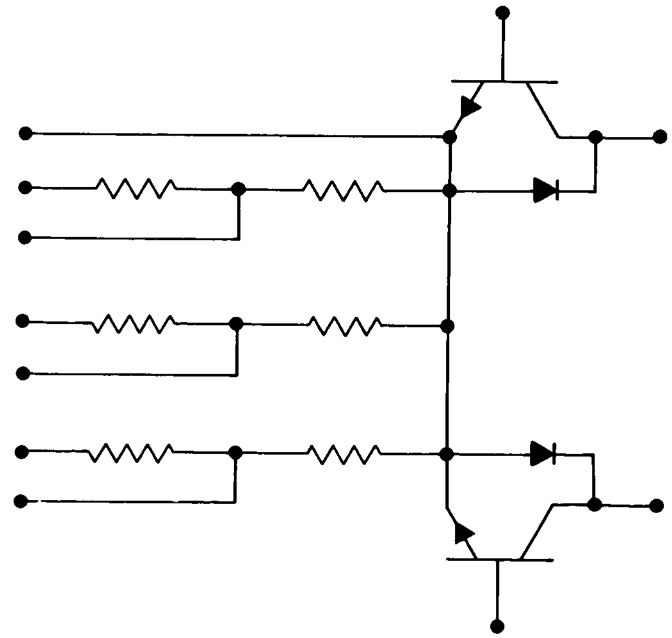

FIGURE 3. SCHEMATIC OF INTEGRATED-CIRCUIT OSCILLATOR/AMPLIFIER

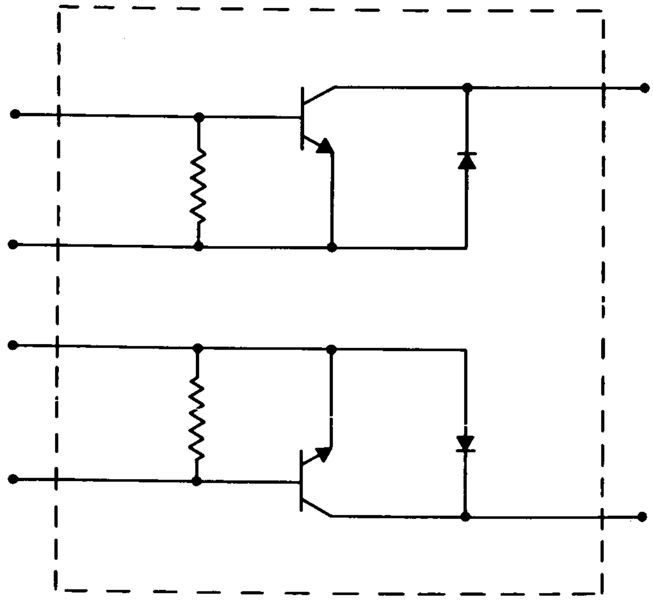

FIGURE 2. SCHEMATIC OF INTEGRATED-CIRCUIT POWER AMPLIFIER

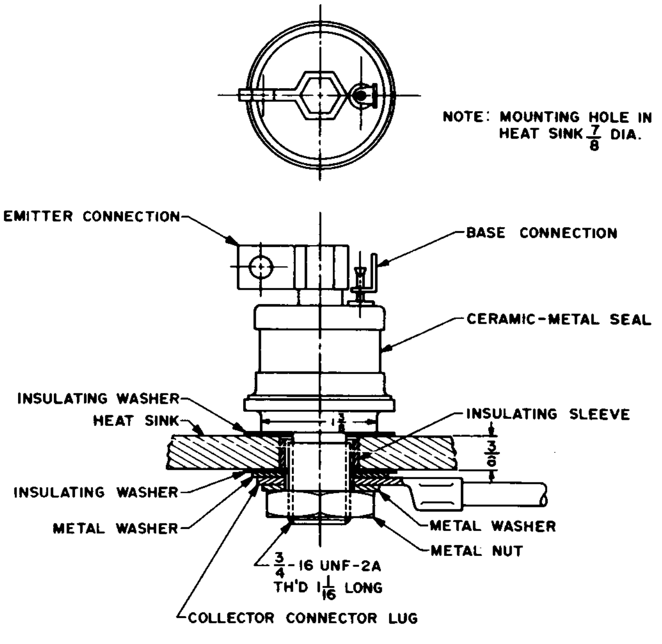

FIGURE 4. 100-AMPERE TRANSISTOR

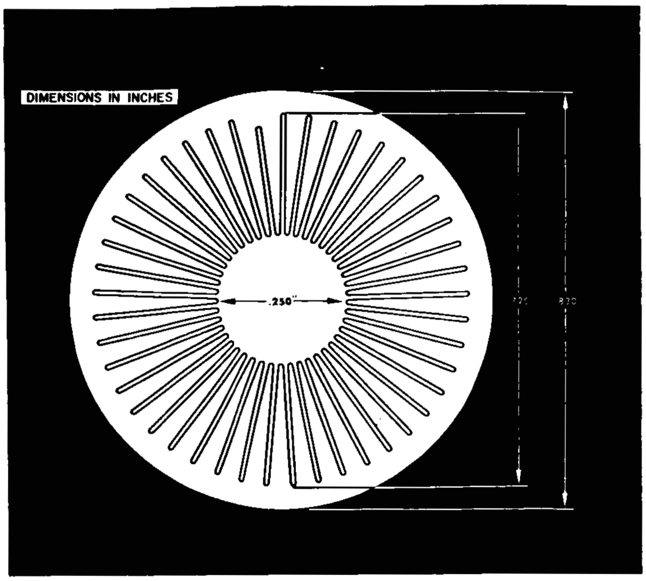

FIGURE 5. 100-AMPERE TRANSISTOR: COMPLETED WAFER

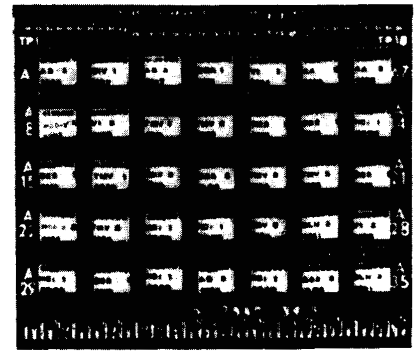

FIGURE 8. ONE PAGE OF THE GUIDANCE COMPUTER

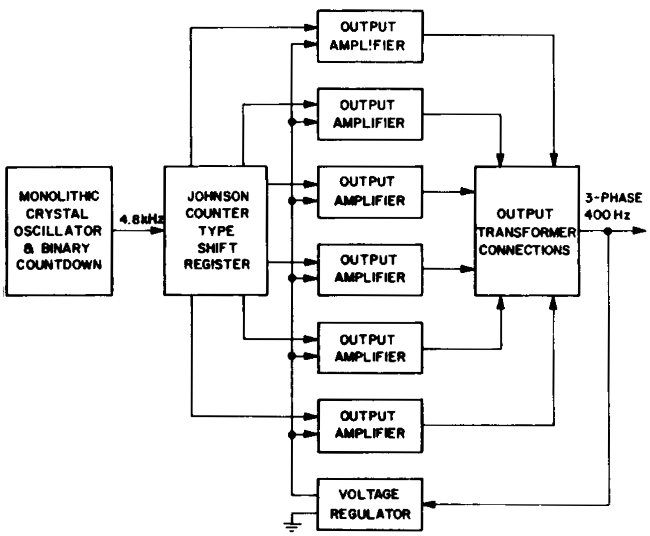

FIGURE 6. STATIC INVERTER USING INTEGRATED ASSEMBLIES

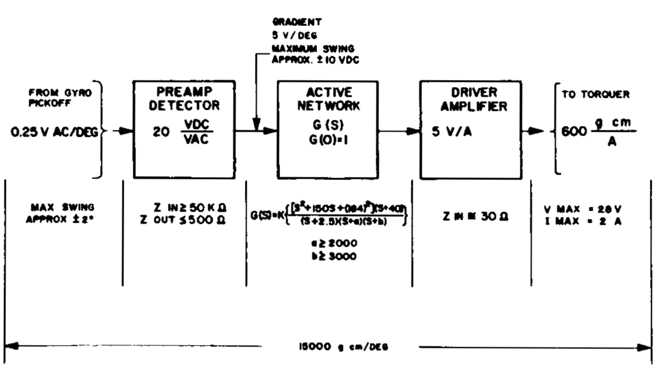

FIGURE 7. GYRO ELECTRONICS

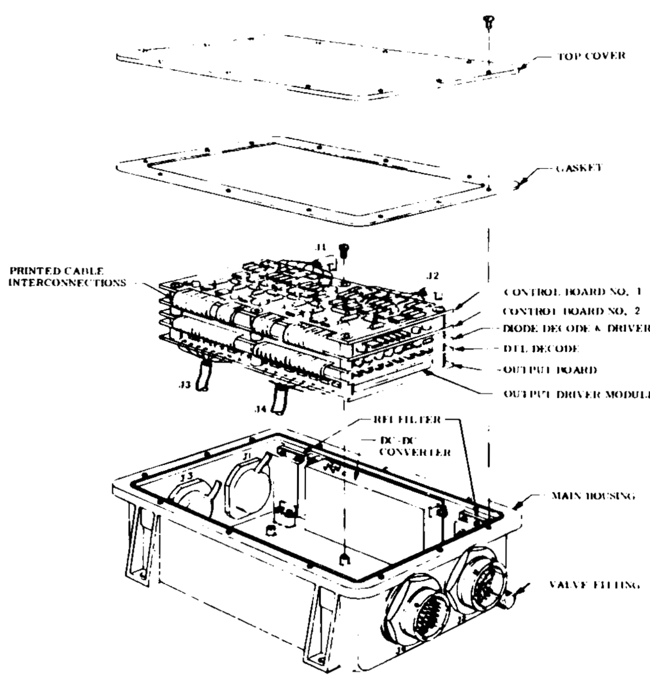

FIGURE 9. SWITCH SELECTOR ASSEMBLY

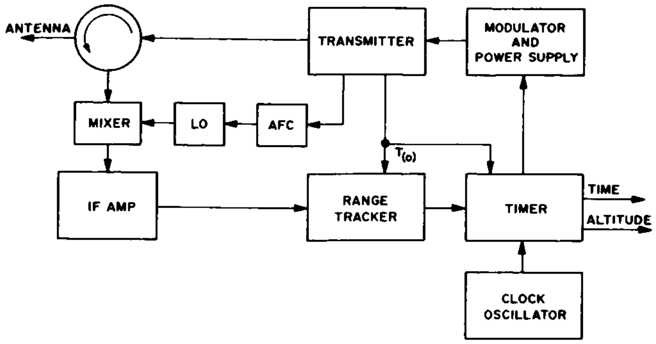

FIGURE 10. BLOCK DIAGRAM OF RADAR ALTIMETER

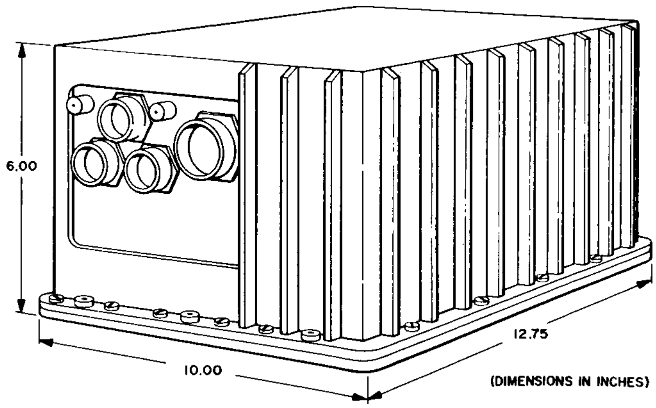

FIGURE 11. RADAR ALTIMETER HOUSING

RESEARCH ACHIEVEMENTS REVIEW SERIES NO. 5

Electronics Research at MSFC

By Joseph L. Randall, James C. Taylor, and Charles L. Wyman

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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James C. Taylor

JAMES C. TAYLOR
Chief, Applied Research Branch

W. Haeussermann

W. HAEUSSERMANN
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In a prepared statement presented on August 5, 1965, to the U. S. House of Representatives Science and Astronautics Committee (Chaired by George P. Miller of California), the position of the National Aeronautics and Space Administration on Units of Measure was stated by Dr. Alfred J. Eggers, Deputy Associate Administrator, Office of Advanced Research and Technology:

"In January of this year NASA directed that the international system of units should be considered the preferred system of units, and should be employed by the research centers as the primary system in all reports and publications of a technical nature, except where such use would reduce the usefulness of the report to the primary recipients. During the conversion period the use of customary units in pa[illegible] [illegible]ing the SI units is permissible, but the parenthetical usage of conventional units will be [illegible] as soon as it is judged that the normal users of the reports would not be particularly inconvenienced by the exclusive use of SI units."

The International System of Units (SI Units) has been adopted by the U. S. National Bureau of Standards (see NBS Technical News Bulletin, Vol. 48, No. 4, April 1964).

The International System of Units is defined in NASA SP-7012, "The International System of Units, Physical Constants, and Conversion Factors," which is available from the U. S. Government Printing Office, Washington, D. C. 20402.

SI Units are used preferentially in this series of research reports in accordance with NASA policy and following the practice of the National Bureau of Standards.